Perception of, and adaptation to, a three-dimensional curvature distortion

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The curvature distortion perceived under water was measured in three dimensions before and after 15 min of adaptation to the underwater environment. Subjects initially perceived distortions in all three dimensions. After 15 min under water, they exhibited significant adaptation to the curvature distortion in all dimensions. The type of task performed while in the water did not significantly affect the amount of adaptation. The results are compared with those of previous experiments which have reported evidence of counteradaptation when more than one kind of adaptation is measured simultaneously.

Due to the differences in the refractive indices of air and water, the virtual image of an object in the water formed through a diver's facemask appears to be magnified to about 1.3 times its physical size and located at about three-fourths of its physical distance. Moreover, this size and distance distortion increases in the periphery, producing a type of curvature distortion known as the pincushion illusion. This causes objects to appear both convex towards the line of sight and convex away from the observer.

Many aspects of these distortions have been investigated singly. Several studies have shown that it is possible to partially adapt to the size and distance distortions under water (Luria & Kinney, 1970; Ono & O'Reilly, 1971; Ono, O'Reilly, & Herman, 1970). Although several investigations have shown that it is possible to adapt to curvature (i.e., perceive a curve as less curved after inspection) in air (Gibson, 1933; Vernoy, 1976; Wallace & Barton, 1975), only one has attempted this in water. Ross (1970) had divers adjust a line of variable curvature so that it appeared just bent toward or away from them before and after a 30-min dive. She reported that, after the dive, they exhibited a 25% adaptation to the initial distortion.

Three-dimensional curvature distortion in the

water has never been fully investigated. It is conceivable that adaptation to all three dimensions simultaneously does not occur. Several studies of adaptation to size and distance under water have reported that adaptation to size was correlated with increased distortion of apparent distance, or vice versa (Franklin, Ross, & Weltman, 1970; Luria, McKay, & Ferris, 1973; Ross, Franklin, Weltman, & Lennie, 1970; Ross & Lennie, 1972). Since the underwater curvature distortion is optically very closely related to the size and distance distortion underwater, it would be interesting to know if divers can adapt to this curvature distortion in all three dimensions simultaneously. A second purpose of this experiment is to study perceptual adaptation to the curvature distortion as a function of different underwater tasks.

METHOD

Subjects

Twelve men and women volunteered to be subjects. Five were Navy divers assigned to the Laboratory and one was an experienced recreational diver. The others had either never dived or had not been diving within the past 6 months.

Apparatus

The apparatus used to measure the curvature distortion in three dimensions is shown in Figure 1. It was essentially a square composed of four white flexible plastic rods whose degree of curvature could be controlled by the subject. The rods were 30 cm long and 6 mm in diameter; the sides of the square subtended a visual angle of 40 deg at a viewing distance of 45 cm. The square was suspended from a sheet of clear acrylic which was virtually invisible when submerged in water. The acrylic was attached to a 60-cm skeleton cube constructed of 2.5-cm-diam plastic pipe. Attached to each plastic rod were four small stainless steel wires which, when pulled, changed the curvature of the rod. Two of the wires controlled movement in the plane of the square (x or y direction), and two of the wires controlled movement perpendicular to the plane of the square (xz or yz direction). Spring tension was applied to two wires on each rod which, when no tension was on the wires, made the cube appear

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Figure 1. The experimental apparatus used to measure the underwater curvature distortion simultaneously in three dimensions.

convex toward the center of the square and concave toward the subject. The remaining wires were attached in pairs to one of four control ropes. Corresponding wires of the two vertical rods were attached to the same control ropes, and corresponding wires to the horizontal rods were attached to the same control ropes. The subject adjusted the curvature of the square in three dimensions by increasing or decreasing the tension on the four control ropes as he/she viewed the square through a 15-cm-diam hole cut in the center of a 60 × 50 cm aluminum sheet that was attached to the front of the cube.

Procedure

The experiment was conducted in a small lake (visibility 3 m). Subjects were first fitted with a wet suit, mask, and snorkel. They were then instructed that their task was to adjust the variable curvature square by pulling on the ropes until the square appeared to be a perfect square, with the centers of all the rods in the same plane as the ends of the rods. The subjects participated in three different experimental trials in the lake. Each trial consisted of (a) a pretest in which the subject knelt in very shallow water, looked through the viewing hole in the front of the experimental apparatus, and adjusted the variable curvature square while in air; (b) a pretest in which the subject knelt in water approximately 4 feet deep, breathed through a snorkel, and adjusted the variable curvature square while under water; (c) a 15-min adaptation period; (d) a posttest in which the subject again adjusted the square underwater; (e) a posttest in which the subject adjusted the square while in air.

The only difference between the experimental trials was the task which the subjects were required to perform during the adaptation period. They either (a) sat on the bottom, breathed through a snorkel, and remained passive during the entire adaptation period; (b) sat on the bottom, breathed through a snorkel, and practiced tying knots in a rope during the adaptation period; or (c) spent the adaptation period in air. Each subject participated in all conditions in counterbalanced order.

RESULTS

After each setting, the lengths of the four control ropes were measured in centimeters. The length of each rope minus its length when the rods were physically straight was a measure of the length of the sagitta of the curve of each flexible rod. This sagitta

measurement, converted to the degree of curvature ($1/\text{radius of curvature}$) of each rod, was the dependent variable. Table 1 gives the results. For clarity of presentation, the percentage of the theoretical optical distortion is reported instead of the degree of curvature used in the statistical analysis. This percentage is 100 times the ratio of the sagitta as adjusted by the subject to the theoretical sagitta for the perpendicular part of the square as predicted by the optics involved in the air-water system. Therefore, if the subject set the square to equal the optical distortion in water, the above percentage would be 100 and if the subject set the square perfectly straight the above percentage would be 0. For the underwater (direct) responses, a positive percentage indicates a response in the predicted or adaptive direction; a negative response indicates a response in the non-predicted or counteradaptive direction. The expected direction of the aftereffect measures are, of course, opposite to those of the direct water measurements. For the air aftereffect responses (pretest-posttest), a negative percentage indicates a response in the predicted or adaptive direction; a positive percentage indicates a response in the nonpredicted or counteradaptive direction.

The pretest underwater values in all conditions were essentially identical, and can therefore be used as an estimate of the actual perceived optical curvature distortion on entering the water. The mean water pretest values for all the subjects for the x, y, xz, and yz curvature measurements were 82.33%, 71.00%, 62.66%, and 57.33%, respectively.

The difference between the pretest and posttest values was the measure of adaptation. Since the theoretical distortion in the xz and yz measurement conditions was more than twice the theoretical optical distortion in the x and y measurement condi-

Table 1
Means for All Conditions of the Experiment as a Percentage of the Theoretical Optical Distortion

Condition	Direct			Negative Aftereffect		
	Pretest	Posttest	Pre-Post	Pretest	Posttest	Pre-Post
Motion						
x	70	30	40	-53	16	-69
y	59	44	15	-65	-12	-53
xz	62	12	50	-1	79	-80
yz	30	-36	66	3	65	-62
Passive						
x	81	43	38	-60	-7	-53
y	70	31	39	-8	40	-48
xz	71	-12	83	17	97	-80
yz	106	50	56	47	30	17
Control						
x	96	116	-20	-13	34	-47
y	84	89	-5	-17	-21	4
xz	55	25	30	-7	-14	7
yz	36	30	6	7	-8	15

tions, separate analyses were performed on these two groups of measurements. The measurements made in air (aftereffect) were analyzed separately from those made in the water (direct measurement). A two-way analysis of variance of the combined and direct x and y adaptation measures showed that the type of adaptation condition was significant [$F(2,66) = 5.31$, $p < .01$]. According to Tukey's test of honestly significant differences (Kirk, 1968), both the motion mean, 27.5%, and the passive mean, 38.5%, were significantly greater than the air control mean, -12.5%, but they were not significantly different from each other.

A similar analysis of variance of the combined direct xz and yz adaptation measures again showed that the adaptation condition was significant [$F(2,66) = 4.79$, $p < .05$]. Both the motion mean, 58.0%, and the passive mean, 69.5%, were significantly greater than the air mean of 18%, according to Tukey's test, but they were not significantly different from each other.

These analyses also showed that, as expected, there were no significant differences between the amounts of adaptation to the x and y dimensions or between the amounts of adaptation to the xz and yz dimensions.

These results are supported by the aftereffects in air. All were in the opposite direction from those in water. Analysis of variance showed that the adaptation condition was significant both for the combined x and y aftereffects [$F(2,66) = 4.96$, $p < .01$] and for the combined xz and yz aftereffects [$F(2,66) = 4.09$, $p < .05$]. In both cases, the motion and passive means were significantly greater than the air mean, according to Tukey's test.

Finally, the mean amount of perceptual adaptation to the x and y dimensions, combined for the motion and passive conditions, was 33%. The mean change for the xz and yz dimensions, combined for the motion and passive conditions, was 63.75%.

DISCUSSION

These results indicate that it is possible to adapt to all dimensions of the three-dimensional curvature distortion under water simultaneously. There was no indication of the "counter-adaptation" reported in the studies cited above. The reason must undoubtedly be that, in the present study, the subjects were adapting to the same class of distortions, even though they were in different directions in space. In contrast, those experiments which found evidence of increased perceptual distortion after a period of adaptation were dealing with both the perceptions of size and distance. These are different classes of perceptions, although they are related to a large extent, as the size-distance invariance

hypothesis postulates (Epstein, Park, & Casey, 1961). The relation between the perceptions of size and distance tends to produce, in most people (Luria et al., 1973), an apparent increase in the perceptual distortions in one class as adaptation occurs to the other class.

Having the divers engage in manual activity did not result in any more adaptation than having them sit quietly in the water during the adaptation period. A consideration of the differences between the two underwater tasks leads to a reasonable explanation. The difference between the active and passive conditions was entirely a motor difference. The task of adjusting the variable curvature square, on the other hand, was almost entirely a visual task requiring no visual-motor coordination. Therefore, the adaptation measures in this experiment consisted almost entirely of visual adaptation, similar to the visual adaptation to curvature distortion produced by prisms in a nonlinear environment reported by Held and Reikosh (1963).

However, in order for adaptation to distorted visual perception to occur, there must be some stimulus, either conscious or unconscious, which indicates to the subject that a distortion exists (Moulden, 1971). In the present experiment, that stimulus was probably provided by the differential velocities of the many suspended particles in the water. These particles are present in all underwater environments. In the lake, natural currents and wind conditions presented a continually changing stimulus array. The visual pattern and information presented to each subject with his eyes open in the water were extremely rich, regardless of adaptation condition, and were, of course, similar during both adaptation conditions. It was presumably this visual stimulation, rather than the assigned tasks, which resulted in the visual adaptation measured in the experiment.

Ross (1970) has reported that experienced divers are not as influenced by optical curvature distortion as are novice divers. In the present study, no significant differences were found between novice and experienced divers in either the xz or yz water pretest conditions (which were comparable to Ross's conditions). The present lack of significance may be due to the high variability among the divers in the present sample. This variability may be attributable to the wide range of diving experience (from 3 to over 20 years). Similar variability among experienced divers has been reported by Kinney, Luria, Weitzman, and Markowitz (Note 1) for several underwater tasks.

The magnitude of distortion perceived when the divers first went into the water was sizable in all three dimensions, but less than the amount predicted optically in each dimension. This is typical. Ross's (1970) subjects also exhibited less than the theoretical

underwater curvature distortion. Such findings are consistent with results obtained from the measurements of resolution acuity and stereoacuity under water, both of which are also less under water than is predicted by the optical magnification at the air-water interface (Luria & Kinney, 1970, 1972; Ross, 1967; Kent & Weissman, Note 2).

Finally, the subjects did not adapt totally to the distortions in any of the experimental conditions. However, the 33% adaptation found in the x and y dimensions is comparable to that typically found in classical curvature and prism adaptation experiments (Bales & Follansbee, 1935; Carlson, 1964; Day & Singer, 1967; Gibson, 1933; Harris, 1965). The 63.75% adaptation found in the xz and yz dimensions is over twice that reported by Ross (1970) under water and by Wallach and Barton (1975) for prism glasses, and it is much greater than that reported in any previous experiment on size and distance adaptation under water.

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