ONR Code 455
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AD684871

January 1969
Report No. 68-61

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Biotechnology Laboratory Technical Report No. 45

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Sponsored by Office of Naval Research Under
Contract No. N00014-67-A-0111-0015

NR 196-069

DEPARTMENT OF ENGINEERING
UNIVERSITY OF CALIFORNIA
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FOREWORD

The research described in this report, "Adaptation of Divers to Distortion of Size and Distance Underwater," Number 68-61, was carried out under the direction of Gershon Weltman, Principal Investigator, in the Department of Engineering, University of California, Los Angeles.

The co-principal investigators were visitors to the Biotechnology Laboratory for the period of this summer study. Helen E. Ross came from the Department of Psychology, University of Hull, England, and Samuel S. Franklin came from the Department of Psychology, Occidental College, Los Angeles.

The project was supported by the Office of Naval Research under Contract No. N00014-67-A-0111-0015.

ACKNOWLEDGMENTS

The authors wish to acknowledge the scientific guidance provided by Dr. Gilbert Tolhurst, Head of the Physiological Psychology Branch, ONR, Washington, D.C. Mr. Peter Lennie, a student at the University of Hull, England, was of invaluable help throughout the study; Experiment V was largely his contribution. Thanks are also due to Dr. Glen H. Egstrom, head of the Performance Physiology Laboratory, UCLA, and Mr. Frank Gasser, of the University of California, Riverside, who assisted with equipment preparation and subject scheduling while involved in other underwater studies.

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SUMMARY

This report describes a series of five experiments conducted during summer 1968 to examine adaptation of divers to size and distance distortion underwater. Visually perceived distortions of size and distance are produced by the diver's face-mask which introduces an air-water interface between the eye and the object of regard. The effect of this interface is to decrease image distance by about one-fourth. Under these conditions objects are likely to be reported as closer or larger, or closer and larger than they actually are.

Previous investigations have demonstrated that a form of perceptual learning or adaptation occurs when persons are exposed to distorted optical stimulation. As exposure is increased the apparent distortion of the visual world is reduced, i.e., individuals report viewed objects at more nearly their true physical size and location. In the present experiments adaptation to distortions of size and distance were investigated by two techniques:
1) the method of adjustment where a diver adjusted the size of a horizontal line, set in the frontal plane at a fixed distance, to a length of 12 inches,
2) the method of estimation where the diver recorded his judgments of the size and distance of a series of targets which varied on these dimensions.

Of the five experiments conducted in the Underwater Research Facility tank and swimming pool at UCLA and in the ocean, three were successful in demonstrating adaptation. All experiments are discussed fully in the body of the report: the remainder of this section summarizes the procedures and major findings.

In Experiment I the method of size adjustment was used by experienced and novice divers in air and in water before and after a 20- to 40-minute underwater exposure period. A comparison of initial water and air settings indicated that both groups perceived the line as enlarged underwater. Significant differences between pre- and post-exposure settings indicated that adaptation to the size distortion (in the amount of about 20%) occurred during the underwater exposure period.

Experiment IV examined size and distance adaptation in experienced divers by the method of estimation. Before and after 20 minutes of underwater exposure in a swimming pool divers estimated the size and distance of an array of targets in air and in water. Pre-exposure judgments indicated that under water the divers experienced significant distortion of distance, yet air and water size judgments were in close correspondence. A comparison of pre- and post-exposure judgments showed, however, that a small but significant amount of adaptation to size occurred during the exposure period. While adaptation to distance was not evident in the major analysis it may have nevertheless occurred for some divers. A correlational analysis of the size and distance adaptation scores suggested that divers may have responded to the optical distortion in different ways. Some adapted to size, some seemed to adapt to distance and some appeared to adapt to both size and distance.

In Experiment V the effect of previous diving experience on underwater size estimation was investigated by the method of adjustment. Novice divers and non-divers were asked to adjust an expandable line to 12 inches both in air and in water with the water settings being made from outside the diving tank looking in through a viewport. The air settings of the two groups did not differ but significant differences were found in the water adjustments. The results suggested that underwater objects appear less enlarged for divers than for non-divers. It is interesting to note in this regard that in the water pre-test of Experiment I, where a similar procedure was used to obtain size judgments, experienced divers tended to adjust the line more accurately than novice divers. Thus, it would appear that previous diving experience is related to the estimated size of an underwater target. While non-divers seem to respond on the basis of immediate optical stimulation, divers apply corrective measures as a function of their diving experience. The correction may be due to previous perceptual learning or to intellectual factors; it is likely that both occurred in the present experiments. Nevertheless, the results indicate that the more experienced the diver the more accurate will be his estimate of the size of an underwater object.

Experiments II and III, which were conducted in the diving tank and ocean respectively, failed to demonstrate adaptation. In Experiment II distance adaptation was investigated by having Ss adjust the location of a post to a specified distance. The measure was relatively crude and subject to extraneous variables which may have influenced the results. Experiment III attempted to measure size adaptation by the method of adjustment by obtaining settings in air before and after a 50-minute ocean dive. It was suggested that adaptation may have been masked by high variability due to increased anxiety associated with an ocean dive, from the inclusion of several relatively inexperienced divers, and by the use of both ascending and descending trials.

In summary the evidence suggests that divers can and do adapt to the distortions of size, and probably to the distortions of distance, that occur in an underwater environment. Adaptation was obtained over a relatively brief exposure period and in different experimental situations using different experimental methods. The data further suggest that since previous diving experience enhances adaptation, special regimens of training and exposure might be used to accelerate and complete the adaptation process.

INTRODUCTION

A diver's face-mask in water acts like a magnifying lens, increasing image size and reducing image distance. These effects are produced by the change in refractive index between water and the air in the face-mask. The image distance is located at about 3/4 of the object's physical distance; approximation is necessary because greater distortion occurs at the periphery of the visual field, causing straight lines to appear curved, and because individual difference in mask fit affect the degree of distortion. Distortion may have an appreciable effect on task performance when the diver is required to estimate the true size and distance of underwater objects or of landmarks in his locale. Selection of proper tool size, description of salvagable objects, and fine-positioning of a submersible are a few of many possible task examples. Accordingly, it is important to determine both how divers initially perceive size and distance underwater, and how perception changes with exposure time and diving experience.

Luria, et al (1967) and Ross (1967) have reported that divers generally overestimated the true size of objects in water. Distance judgments in water appear to be influenced by the conditions of viewing. At relatively near distances divers tend to underestimate true distance but overestimate the assumed optical distance. Underwater estimations of far distances tend to exceed land judgments (Ross 1965). Low brightness contrast has been hypothesized as an important factor in underwater judgments of far distances (Ross, 1968). Although there is little evidence regarding a divers capacity to adopt to visually perceived distortions of size and distance the results of other investigations on adaptation to distorted vision suggest that it would occur.

In 1903 Stratton wrote, "Doubtless some enthusiast will one day try the experiment of wearing glasses that make all things appear twice or thrice or half as large as they normally do." On the basis of his earlier findings Stratton predicted that with continued wearing of the glasses an observer would eventually perceive objects as undistorted in size. Rock (1965, 1966) was among the first to attempt such an experiment. He found size adaptation to distortion produced by a convex mirror system which made objects appear smaller but at the correct distance. However, he failed to find adaptation when subjects looked through a minifying lens system, and suggested that this was because the system made objects appear further rather than smaller. Similarly Thouless (1968) found that a magnifying system made objects appear nearer rather than larger. Ross (in press) found that divers adapted to curvature distortion during the course of a 30-minute period underwater. She also found that experienced divers showed greater initial adaptation than novices immediately upon entering the water. On the other hand, informal observations reveal that fish, lobster, etc., appear overly large underwater even for experienced divers, suggesting that full adaptation to size and distance distortion may never occur.

Two methods of measuring adaptation to distorted vision have been employed by previous investigators. Kohler (1964) compared judgments of the visual world at the beginning and at the end of the period during which a distorting system was worn. If the observer adapts to the optical distortion, objects in the environment should appear less distorted at the end of the exposure period. Roch (1965, 1966) and others (e.g., Held and Gottlieb, 1958) obtained an indirect measure of adaptation by examining the aftereffect which remains following the exposure period. If a change in perception occurs while wearing a distorting optical system it might be expected to persist for a short time after the removal of the system. Thus, judgments (made without the system) before and after the exposure period would differ. While the aftereffect dissipates rapidly and is therefore the more difficult to measure, Rock suggests that it is free of confounding by intellectual factors which the observer may employ in an attempt to correct for the known distortions of the optical system.

In the present study, five experiments were conducted to investigate adaptation to size and distance distortion in divers. Two methodological approaches were used. In Experiment I size adaptation was examined using the method previously employed by Rock. Divers adjusted a horizontal line to a standard length immediately prior to entering a tank, immediately upon entering, after 20 to 40 minutes underwater and immediately upon leaving the water. Adaptation was measured directly by comparing adjustments in the water, and indirectly by measuring the post-exposure aftereffect. In Experiment II a variation of the same technique was used to examine distance adaptation. In Experiment III the indirect measure of aftereffect was applied to examine size adaptation during ocean exposure. In Experiment IV, adaptation was measured by comparing size and distance estimates of randomly arrayed targets at the beginning and end of a 30-minute swimming pool exposure. Experiment V focused on the effect of previous diving experience on size adjustment; divers and non-divers stood outside a diving tank and adjusted an underwater line to a standard length as in Experiment I. Experiments I, IV and V were relatively successful, while Experiments II and III were less so in providing information concerning perceptual adaptations.

EXPERIMENT I

SIZE ADAPTATION BY METHOD OF ADJUSTMENT IN THE TANK

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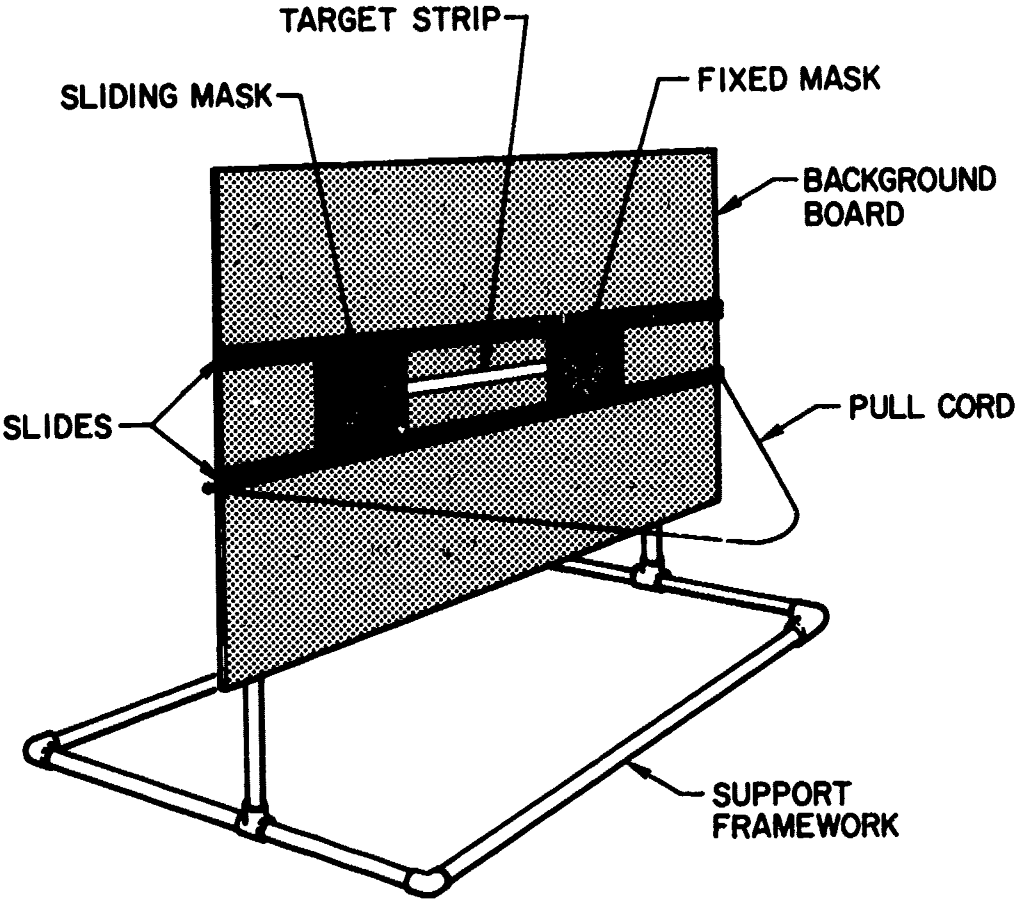
This experiment was performed to investigate whether size adaptation occurred in a well-structured visual environment underwater, and to see if there were any differences between novice and experienced divers.

Method

Apparatus: Figure 1 illustrates the adjustment apparatus. A 5/16-inch-wide strip of buff-colored masking tape was fixed horizontally across the center of a 4-foot by 8-foot sheet of black masonite, which was supported by a pipe framework. Two 20-inch-long rectangular black masks were set onto slides and could be moved across the strip. A thin nylon cord was connected to both ends of the left-hand mask after passing through eyelets located at the ends of the board. The subject sat on a stool in front of the board. With the right-hand mask fixed, pulling on the card uncovered more or less of the central strip. Movement of the cord against the board was hidden by the lower slide. The board filled the subject's field of view when he wore a face-mask, and his hands were not visible while he pulled the cords.

Two identical adjustment boards were constructed for simultaneous use above and below the surface. The boards were set on the floor of the UCLA Underwater Facility diving tank, and on a platform crossing the tank at water level, so that the subject could be tested in air immediately after leaving the water. The free-standing diving tank is 15 feet in diameter and 15 feet deep. It is equipped with air hoses for two divers, and water temperature is maintained at about 80°F. During the control experiments, a board was erected on a scaffolding frame on the ground beside the tank.



SIZE ADJUSTMENT APPARATUS

Figure 1

Subjects: The experienced diver group was composed of 11 males, mainly university staff and students, with diving experience ranging from 1-15 years. The novice diver group was composed of 11 male trainees from a university SCUBA course, who had completed about 8-hours' training in the swimming pool. A control group was composed of 14 psychology students and workshop personnel.

Procedure: The diver subjects, wearing face-masks and 'hookah' breathing gear, sat on the tank platform 3 feet from the air test board. They were instructed to adjust the position of the left-hand mask until they thought the strip of tape between the masks was 12-inches long. They were given no training on this task, since a preliminary experiment showed that brief training did not significantly reduce variability. The experimenter moved the position of the right-hand mask between each trial, to prevent the subject from using minor marks on the board as reference points. The subject made four settings, always starting with the two masks close together. Between each trial the subject looked away while the experimenter measured the setting with a ruler. The four size judgments took about a minute.

After the air adjustments the diver descended to the bottom of the tank and immediately performed the same test at the same distance. He was instructed to do the same thing underwater as he had done in air. A few subjects asked whether they should correct for the optical effect. These subjects were told, "Do what you normally do when you estimate sizes and distances underwater."

After the first set of water judgments the subject remained underwater for at least 20 minutes. During this time he played pegboard games and built castles with Coca-Cola cans. It was assumed that these activities would provide information about objects of known size, and thus facilitate size adaptation. Some subjects worked for about 40 minutes on an underwater construction task, as part of another experiment. These subjects also played with the Coca-Cola cans. There was no evidence that the increased length of time underwater or the difference in occupation had any effect upon adaptation. After the adaptation period the subjects were retested underwater. They then ascended and were retested in air within 15 seconds of surfacing, still wearing their face-masks.

The control subjects made four sets of four size adjustments in air, at approximately the same time intervals as were used in the diving experiment. There was a 1 minute interval between sets 1 and 2 and between sets 3 and 4, and a 20-minute interval between sets 2 and 3. During these intervals the subjects walked around or read a book.

Results and Discussion

The mean size settings for the divers and controls on the first trial only, and on all four trials combined, are shown in Table 1. The main tests of significance were for the difference between initial pre-test trials, in air and water, the difference between pre- and post-test trials in air, and the difference between pre- and post-test trials in water.* The two latter differences represented measures of adaptation. The controls showed no significant differences between any trials, thus indicating that repetition at the present intervals did not in itself affect response. For both groups of divers the water settings were significantly smaller than the air settings, both for the first trial and for the means of all four trials ($p < 0.005$). Experienced and novice divers produced larger settings in the post-tests than in the pre-tests, suggesting that adaptation had occurred during the exposure period. The differences were not significant for the means of all four trials, but they were significant for the first trial only, for all groups except the novices in water.

The failure to find significant adaptation over all four trials in air is readily explained by the rapid fading of the aftereffect (see Rock, 1965). The size of the settings tended to decrease from trials 1-4, and return to

*Non-parametric tests (mainly Wilcoxon's T and Mann-Whitney U) were used throughout, because of the small number of subjects, and differences in variability between groups and conditions.

Table 1

Mean size settings of 14 controls, 11 experienced divers and 11 novices, when estimating 12 inches. The "water" settings of controls were run in air.

	AIR				WATER			
	Pre-test Trials		Post-test Trials		Pre-test Trials		Post-test Trials	
	1	1–4	1	1–4	1	1–4	1	1–4
Cont.	12.04	11.99	12.21	12.16	11.91	12.18	12.16	12.09
Exp.	11.96	12.10	12.55**	12.26	10.33	10.54	10.65*	10.68
Nov.	11.80	11.82	12.49*	12.13	9.55	9.58	9.65	9.61
Comb. Divers	11.88	11.96	12.52†	12.19	9.94	10.06	10.15*	10.14

*Post-Pre $p<0.05$
**Post-Pre $p<0.025$
†Post-Pre $p<0.005$

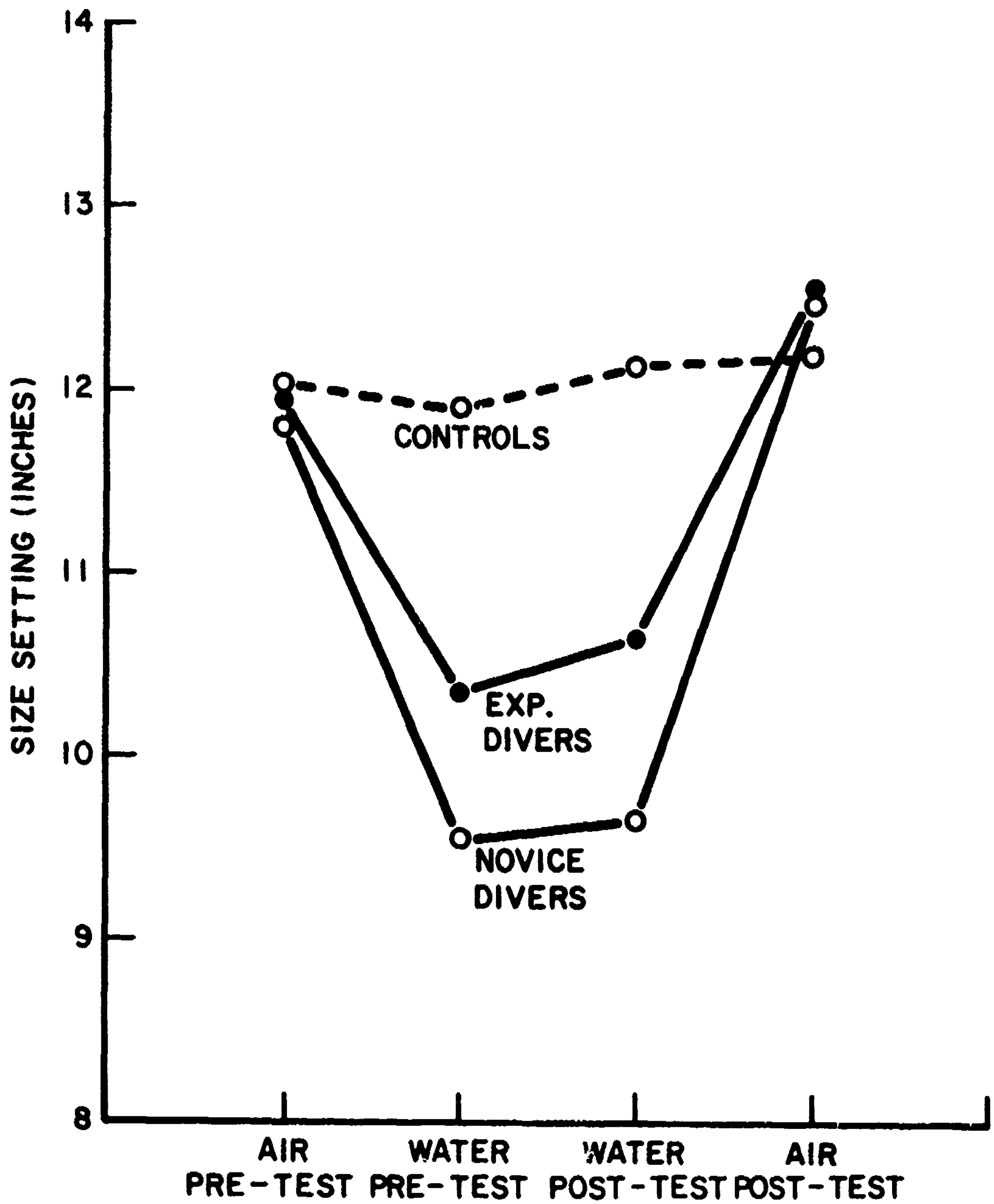
the size of the pre-test settings. The downward trend was significant for all divers combined ($p = 0.034$) on Jonckheere's (1954) non-parametric test for trends. The controls showed no such trends. The difference for the divers was most clearly marked between trials one and two ($p < 0.005$). Despite the rapid fading of the aftereffect, the total diver group still showed a significant aftereffect when the first two trials were combined ($p = 0.026$). This was the criterion used by Rock (1965) in demonstrating that adaptation had occurred. The controls showed no significant effect on this criterion.

The failure to find a significant effect over all four trials in water is more difficult to explain. One hyposthesis might be that divers show rapid adaptation in the water, so that their settings increase over trials 1-4 of the pre-test (the opposite of the fading of the aftereffect in air). This was not borne out statistically, though there was a slight trend in that direction. Another hypothesis is that the higher variability of the difference scores for the means of four trials as compared with the first trial only ($p < 0.025$) mashed any adaptation effects. The novices were more variable than the experienced divers in their pre- and post-test differences on the means of four trials ($p < .001$). One might thus expect to find a significant adaptation effect over all four trials given a large enough group of experienced divers.

Figure 2 shows graphically the changes occurring in mean first-trial settings of the control, novice and experienced groups during the course of the experiment. Both diver groups estimated closely the 12-inch distance on their initial air trial. The settings decreased markedly underwater, more for the novices than for the experienced divers, and shifted upward somewhat following the underwater exposure. There was a distinct and similar aftereffect upon the return to the surface. The failure of the novices to show a statistically significant shift in the water was probably due to their high variability. Their difference scores for the first trial on the pre- and post-tests were significantly more variable than those of the experienced divers ($p < 0.005$), and those of the controls ($p < 0.01$). The three groups did not differ from each other in air on the same measures of variance. The high variance of novices underwater has been noted before on several perceptual tests (Nichols, 1957; Ross, et al., in press).

A comparison of the pre-test air and water settings of the novice and experienced divers is of some interest. Concurrently obtained distance data (see Experiment II) seemed to indicate that apparent distance was quite near physical distance underwater. If size constancy is the same as in air, apparent size should be enlarged by about 4/3, and the size settings in water should be 3/4 of their air values. However, the water settings obtained were larger than would be predicted by the size-distance invariance hypothesis. The ratios of the water to air settings on the first trial were 0.86 for the experienced divers and 0.80 for the novices. This seems to imply that size-distance invariance does not hold in water, that some perceptual learning has occurred previously, or that the divers are making an intellectual correction. Alternatively, the actual distortion ratio of these particular masks may be close to the 0.81 figure shown by the novices.

It seems impossible to differentiate on present evidence between perceptual learning and intellectual correction as explanations for the



MEAN SIZE SETTINGS ON FIRST TANK TRIAL FOR CONTROL SUBJECTS,
NOVICE AND EXPERIENCED DIVERS

Figure 2

larger settings in water by the experienced divers. It is likely that some experienced subjects were setting the line "too large" because they expected a "magnified" image on theoretical grounds. It is likewise impossible to say precisely what percentage of size adaptation occurred over the adaptation period, because it is not clear what the initial magnification effect is. The aftereffect in air showed a mean shift of 0.64 inches from an initial setting of 11.88 inches. If it is assumed that there is 4/3 magnification, and that complete adaptation would lead to an air setting 4/3 larger (15.80), then the adaptation was 16.33%. The initial water settings of the novices suggest that the apparent magnification was less than 4/3, so that the percentage adaptation is probably much nearer Rock's (1965) value of 23%.

EXPERIMENT II

DISTANCE ADAPTATION BY METHOD OF ADJUSTMENT IN THE TANK

Rationale

This experiment was performed to examine the occurrence of distance adaptation under the same well-structured conditions of Experiment I, using novice and experienced divers.

Method

Apparatus: The size adjustment board of Experiment I was used in a subsidiary role. Distance adjustment was performed by placing a vertical weighted post a judged 2 feet from the edge of the board.

Subjects: The same novice and experienced groups as in Experiment I were employed. However, because the distance experiment was begun late, only 8 experienced divers were included. There was no control group.

Procedure: This experiment was conducted simultaneously with the previously described size experiment. After each set of size judgments, the subjects were required to make a single distance judgment. They stood up and placed a post at an estimated 2 feet from the edge of the board perpendicular to the plane of the board and in front of it.

Results and Discussion

The mean distance judgments for the divers are shown in Table 2. There were no significant differences between the air and water judgments. This result suggests that apparent distance was near physical distance for these divers and that there was therefore no stimulus to adapt to distance, or that bodily cues involved in placing the post overcame all perceptual distortion effects. Alternately, the divers may have been making an intellectual correction while still perceiving underwater distances too close. In this case adaptation would lead to their seeing objects further away, and thus getting the post nearer. There was a strong trend in this

Table 2

Mean distance settings of 8 experienced divers and 11 novices, when estimating 24 inches.

	AIR		WATER	
	Pre-test	Post-test	Pre-test	Post-test
Experienced	21.91	22.33	21.56	21.31
Novices	22.99	23.60	23.73	21.91
Combined	22.54	23.06	22.82	21.66*

*Pre-Post, p = 0.058

direction for all divers combined ($p = 0.058$), and we cannot be sure that significant adaptation would not be demonstrated with a larger sample or a better measure of distance perceptions. The failure to find any after-effect in air is not surprising, since any effect would have dissipated by the time the size judgments were completed.

EXPERIMENT III

SIZE ADAPTATION BY METHOD OF ADJUSTMENT IN THE OCEAN

Rationale

This experiment was intended to examine size adaptation effects in the ocean, assumedly a less structured environment than the tank or swimming pool. Unfortunately, scheduling difficulties with the diving boat forced this experiment to be performed first, before the one in the tank. Only one adjustment board was ready, so that adaptation had to be evaluated by the air aftereffect alone.

Method

Apparatus: The size adjustment board was as described for Experiment I. It was fastened to posts at the stern of a diving boat anchored off Santa Catalina Island.

Subjects: The subjects were 14 divers, mainly university staff and students, with diving experience ranging from about 1-15 years.

Procedure: The subject stood on a lower platform, at the stern of the boat, with his head 3 feet from the center of the board. The subjects were tested in air wearing their face-masks, and then went for a 50 minute dive among off-shore rocks with their diving partners. During this time they played for about 5 minutes with a peg-board game, and inspected the marine life. They then returned to the boat and waited with their heads underwater until it was their turn to be retested in air. When they emerged from the water they were retested within about 20 seconds, while still wearing their face-masks and diving gear. In this experiment the subjects made 8 line settings in both the pre-test and the post-test. The line adjustments were alternately ascending and descending.

Results and Discussion

There were no significant differences between the pre-test and post-test settings, either on the mean of the eight settings (12.33 and 12.26 inches) or on the first trial only (12.18 and 12.07 inches). Seven subjects showed an adaptive shift on the first trial, and seven a non-adaptive shift. There are several possible reasons for the failure to find a significant aftereffect as a result of an ocean dive. One is that the aftereffect may have faded before retesting began. Another possibility is that the ocean provides insufficient visual information about size for adaptation to occur. Another possibility is that the variability of the size-judgments was too high: variability may have been increased by anxiety in the ocean, by the inclusion of some relatively inexperienced divers, and by the use of both ascending and descending trials (the descending trials were significantly larger than the ascending trials). Six of the experienced divers also served in the tank experiment (Experiment I), and most of these subjects showed an aftereffect in both experiments.

There seems to be no reason why size adaptation should not occur on an ocean dive since Ross (in press) found curvature adaptation under similar conditions. We are inclined to suspect that in this experiment the failure was due to the high variability of some subjects.

EXPERIMENT IV

SIZE AND DISTANCE ADAPTATION BY METHOD OF ESTIMATION IN THE POOL

Rationale

The size-distance invariance hypothesis predicts three possible effects of viewing an underwater target through a face-mask. The target may be reported at the optical distance and of the correct size; it may be reported at the actual distance and considerably enlarged; or it may appear at some intermediate distance and proportionately enlarged. If perceived distance underwater lies beyond the optical distance, but not at the physical distance, the conditions for both size and distance adaptation are present. In Experiment III adaptation to both dimensions was investigated by the method of written estimation. The procedure employed was expected to provide a more adequate measure of distance perception than that used in Experiment II.

Method

Apparatus: Lengths of 1/2-inch doweling were cemented into tin cans of various sizes, cut to either 6, 9, 12, 15 or 18 inches above the top of the can, and painted black. A set of 10 such dowels, two of each size, constituted the target stimuli. One set was arranged at the shallow end (5 feet deep) of a swimming pool; the pool bottom was level for several feet beyond the furthest target. Another set was similarly arranged on a large, flat, open parking area near the pool. The mean dowel size was 12 inches, the mean target distance was 8.8 feet.

Subjects: Eleven experienced divers and 15 controls (non-divers) served as subjects. The divers were volunteers from an advanced diving program and had approximately 3 years average diving experience. The control subjects were volunteers recruited from the university campus.

Procedure: Subjects estimated the size and distance of the stimuli. In air a rope was stretched across the flat area and provided a line from which the subjects viewed the targets. The targets were arranged behind the rope as follows: two 6-inch targets at 15 feet, two 9-inch targets at 12 feet, two 12-inch targets at 3 feet, two 15-inch targets at 9 feet, and two 18-inch targets at 5 feet. The subject, wearing a face-mask, knelt at the rope and recorded his estimates of each target on a 3 x 5 index card. The targets were spaced approximately 3 feet apart and the subject knelt before each one, proceeding from left to right. The order of targets was determined by placing them in two groups of 5 (one of each size per group) and randomizing the order within a group.

Following the air judgments (air pre-test) the diver subjects went directly to the pool, being careful to avoid looking into the water until submerged, and judged the size and distance of the water targets (water pre-test) arranged similarly but in a different order. The dowels were placed approximately 5 feet apart, one in each swimming lane (lane lines were clearly visible but were parallel to the subject's line of sight). The subject recorded his size and distance judgments on a specially prepared plastic board.

Upon completing the water pre-test the divers proceeded to the deep area of the pool where they remained submerged for the entire adaptation period. During this period they explored the bottom, stacked soft drink cans and engaged in free diving around the area. After approximately 20 minutes they returned to the shallow end of the pool where they again judged the size and distance of the water targets (water post-test), whose order had been altered from that of the water pre-test. When the last water target had been judged the subject left the pool, quickly removed his diving equipment except for the face-mask and ran to the area of the air targets, where he was retested on a new order of stimuli (air post-test).

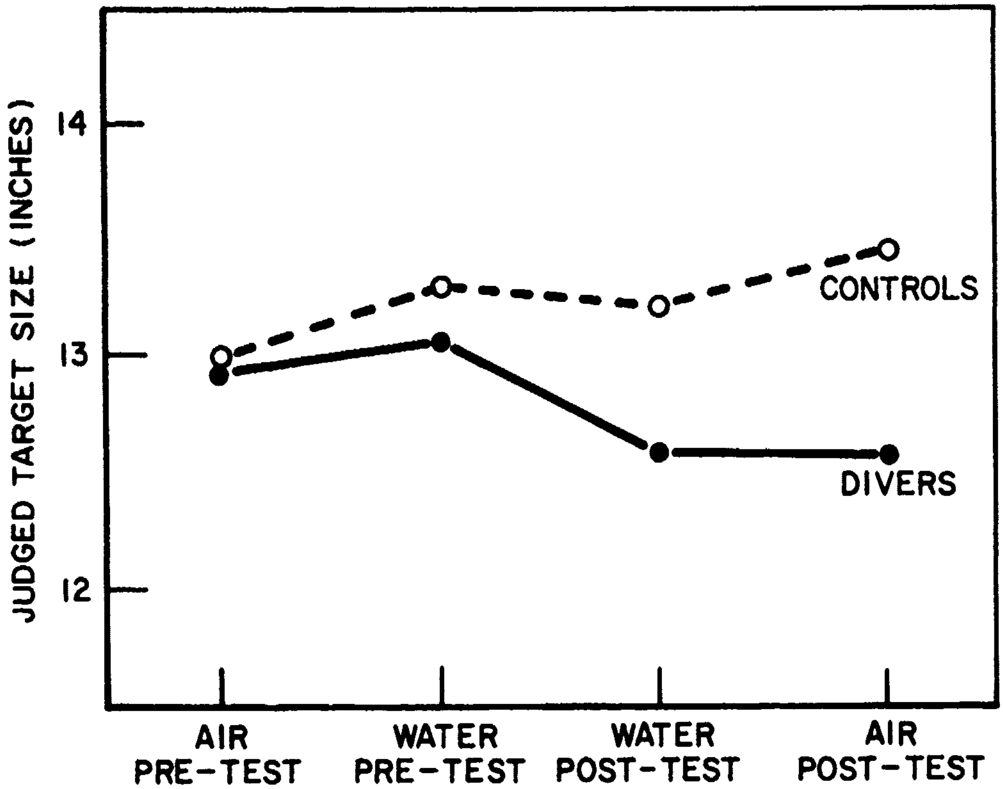
The procedure for the controls was similar except that both the air and "water" targets were judged only in air on a lawn adjacent to a swimming pool and the "adaptation period" was spent in pool-side lounging or swimming. For each test the subjects recorded their judgments on a separate card. Following the air pre-test the subjects judged the "water" targets which were arranged in a different order (the same order as employed in the diver condition) approximately 20 yards away from the site of the air set. They were then instructed to return 20 minutes later, at which time their "water" post-test and air post-test were administered. The order of targets for the post-tests remained the same as in the pre-tests but the subjects judged them from right to left rather than left to right.

Results and Discussion

Figures 3 and 4 present the mean size and distance judgments, respectively, of the diver and control groups during the course of the experiment.* Divers and controls demonstrated quite similar judgments in their initial air pre-test; both groups tended to overestimate mean target size, and underestimate mean target distance. For the control subjects, Wilcoxon tests on the means of the size and of the distance judgments over all targets indicated no significant differences among any of the observation conditions.

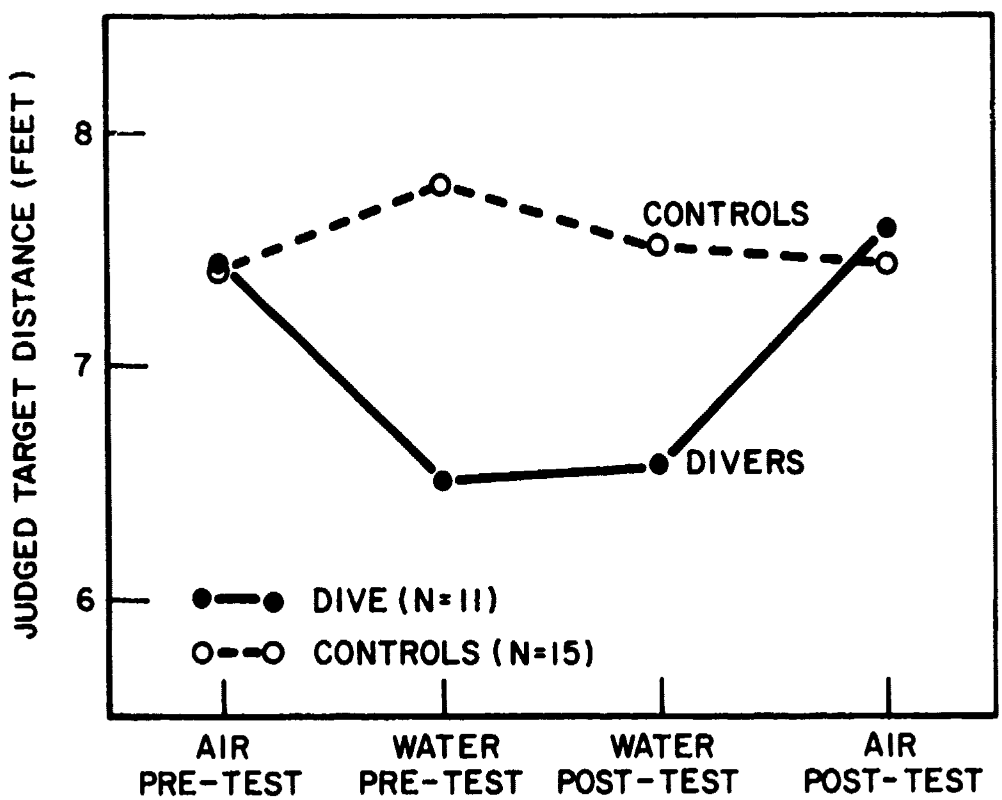
For divers, statistical analyses indicated a significant difference between pre-test judgments of distance in air and water. Water judgments were underestimated relative to air judgments. An analysis of the pre- and post-test distance judgments indicated no significant adaptation to the underwater distance distortion. A significant pre- and post-test difference in underwater size judgments suggests that size adaptation did obtain. This resu' is complicated, however, by the finding that air and water pre-test judgments of size did not differ significantly. On

*The data upon which these figures are based appear in Appendix A.



MEAN SIZE JUDGMENTS FOR DIVERS AND CONTROLS

Figure 3



MEAN DISTANCE JUDGMENTS FOR DIVERS AND CONTROLS

Figure 4

the one hand it appeared that adaptation to size distortion occurred but on the other no evidence of size distortion was obtained. Alternate explanations for the absence of a significant difference between air and water pretest judgments are possible. Underwater estimates may be confounded by intellectual corrections (cf. Rock, 1966, p. 11). Due to previous experience, divers may partially adapt immediately or very soon after entering the water. The difference in initial size estimates of novices and experienced divers in Experiment I lends support to this hypothesis. Thus the initial judgments in water may reflect a combination of "situation-contigent" adaptation (see Kohler, 1951) and an intellectual correction. The combined effects of these factors may explain the absence of a difference between air and water pre-tests. Since the intellectual correction might be expected to remain constant throughout the test periods, it could not account for the change from pre-test to post-test. This change appears to be due to further perceptual adaptation.

In addition, adaptive perceptual response to optical distortion can take several forms. The subject can alter his response to image size or to distance or to both. The data suggest that the mode of resolution varied among the divers. A Spearman rank order correlation test on the size and distance adaptation values (the difference scores between pre- and post-tests sums) revealed a significant inverse correlation (rho = -.71; p = .025). As shown in Table 3, subjects who showed the greatest size adaptation failed to adapt to distance while those who showed little or no adaptation to size demonstrated the predicted shift in distance judgments. The fact that there was no significant adaptation to distance is explained by the finding that most subjects adapted to size.

In some cases, size adaptation seems to have been produced at the expense of increased distance distortion. An inspection of Table 3 reveals that those subjects who showed the greatest adaptive shift in size judgments also decreased their distance judgements from pre- to post-test (a "non-adaptive" distance shift). This trend is also apparent for two of three

Table 3

Size and distance adaptation
Values for 11 divers*

Subject	Size Adaptation (in.)	Distance Adaptation (ft.)
8	– 6.0	6.0
2	– 2.0	3.5
3	1.0	–4.5
6	2.0	1.5
4	3.0	4.0
5	6.0	–3.0
9	7.0	2.7
1	9.0	1.0
10	10.0	–9.5
11	11.0	–9.5
7	15.0	–4.5

*Values represent pre- and post-test differences summed over all target judgments. Positive values represent an adaptive shift and negative values represent a non-adaptive shift.

subjects who showed the greatest adaptive shift in distance estimates. These subjects appear to have adapted to distance by "anti-adapting" to perceived size. Thus, in accord with the size-distance invariance hypothesis, some subjects appear to have adapted on one dimension by distorting the other. Those subjects around the center of the distribution appear to have resolved the conflict by adapting to both size and distance. The data suggest, then, that while significant distance adaptation was masked by the tendency toward size adaptation, it may have nevertheless occurred for some subjects.

It is noteworthy that adaptation to both size and distance requires an inversion of the normal size-distance invariance relation in order to establish the equivalent of land size constancy underwater. Despite the difficulty of such an inversion, the mean results for all divers show a trend in this direction. Table 4 shows the mean size and distance judgments in air and water, and the ratio of the size to distance judgments. The judgments of the controls were fairly stable over all conditions, whereas the

Table 4

Mean size and distance* judgments over all stimuli, and the ratios of the judgments.

Divers	AIR		WATER	
	Pre-test	Post-test	Pre-test	Post-test
Size	12.89	12.58	13.08	12.63
Distance	7.44	7.60	6.49 (8.63)	6.56 (8.70)
S/D	1.73	1.66	2.02 (1.52)	1.93 (1.45)
Controls				
Size	13.05	13.41	13.35	13.17
Distance	7.41	7.40	7.76	7.55
S/D	1.76	1.81	1.72	1.74

*Water distance judgments multiplied by 4/3 (optically equivalent to air judgments), and optical size-distance ratios are shown in brackets.

divers showed both a decrease in size and an increase in distance judgments from the pre- to the post-tests. This means that the ratio of size to distance judgments in water shifts toward the value for the pre-test air judgments, and away from the value expected purely on the basis of the optical distortion.

The judgments of size and distance, and the size-distance ratio, also tended to shift in the corresponding direction in the air post-tests. However, neither the size nor the distance shift was significant. This is scarecly surprising, since the aftereffect fades quickly. In this experiment the subjects were occupied for about 40 seconds in removing their diving gear and running the 30 yards from the pool to the air test site.

EXPERIMENT V

THE EFFECT OF DIVING EXPERIENCE ON SIZE ADJUSTMENT FROM OUTSIDE THE TANK

Rationale

Experiment I showed marked differences in underwater perception between novice and experienced divers. The experiment described below was performed to examine the differences between divers and completely non-diving subjects by the same method. Since the non-divers could not be expected to perform underwater, all the water tests were carried out with the subjects in air looking through a glass porthole.

Method

Subjects: The diving group was composed of 12 divers most of whom were novices from the same SCUBA class mentioned in Experiment I. Many of them had taken part in Experiment I. The non-divers were 10 psychology students, university staff and technicians.

Apparatus and Procedure: The air and water test boards were as described in Experiment I, except that the water board was erected inside the tank facing the porthole at a distance of 3 feet from the glass. During the water tests the experimenter adjusted the length of line from inside the tank while out of sight of the subject. The subject communicated with the experimenter by tapping on the side of the tank to indicate "larger," "smaller" or "O.K.". The subjects made four ascending settings in air and four in water. Half were tested in air first, and half looking into water first.

Results and Discussion

Table 5 shows the mean settings in air and water for the divers and non-divers, for the first trial and for the mean of four trials. The water settings of the divers were not significantly different than their air settings, while those of the non-divers were significantly smaller ($p < 0.005$). The water settings of the non-divers were also significantly smaller than those of the divers ($p < 0.001$), while their air settings were almost identical.

Table 5

Mean size settings of 12 divers and 10 nondivers when estimating 12 inches in air and when looking into the water-tank.

	AIR		WATER	
	Trial 1	Trials 1–4	Trial 1	Trials 1–4
Divers	11.52	11.45	10.80	11.06
Non-divers	11.10	11.47	8.35*	8.50*

*Air-Water $p < 0.005$

The non-divers clearly saw objects in the tank greatly enlarged. The ratio of water to air judgments was 0.741, very near the value of 0.75 which is predicted if apparent distance is accepted as physical distance. The ratio for the divers was 0.966, showing almost no effect from looking into the water. This could be either because divers see objects much nearer than novices, or because they correct for enlarged apparent size. A supplementary study was conducted to investigate these alternatives.

In the supplementary investigation 11 non-diving students from a beginner's swimming class at UCLA were used as subjects. The swimmers served in a modified version of the swimming pool experiment (Experiment IV). With a diving mask in place they judged the set of 10 targets in air and the equivalent water targets at the bottom of the pool. Judgments were recorded as in Experiment IV and the order of the targets was the same. During the water test, however, the subjects submerged themselves momentarily to view the targets rather than remaining underwater through all judgments as the divers had done. The air judgments were obtained first; no post-tests were administered.

Mean air and water size judgments, when taken over all targets, were 11.60 and 12.47 inches respectively. These were significantly different at the 0.01 level. The distance estimates also indicated an effect of underwater viewing. Mean air and water distance judgments were 6.41 and 5.61 respectively ($p < .01$). The results of the size estimates confirm the finding that non-divers experience enlargement of apparent size under water. This distortion obtained with both the line adjustment method and the written estimation method.

The results show also that non-diving swimmers underestimate distance in water. The degree of underestimation was very similar to (and did not differ significantly from) that shown by the divers in Experiment IV. This suggests that the difference in size perception between non-divers and divers cannot be explained purely by a difference in distance perception. The swimmers' size estimates underwater were not as enlarged as might be predicted from their overestimation of the optical distance. The ratio of water to air size judgments was 1.08, while the overestimation of the optically corrected air distance was 1.17.* This suggests that even a naive subject makes some correction for the optical effect. This may be partly due to intellectual knowledge of the optical effect; or, more likely, it may be due to visual and proprioceptive information which is available to the subject during a brief period underwater.

*The equivalent ratios in Experiment IV were 1.02 and 1.25.

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APPENDIX A

Tabulated Data for Experiment IV

Table A–1

Mean size judgments for 11 divers and 15 controls.

Target Size (inches)	PRE-TEST 6(15)*	9(11)	12(3)	15(9)	18(5)	POST-TEST 6	9	12	15	18	X̄ Pre-	X̄ Post
AIR												
Divers	6.3	10.3	12.4	15.6	19.8	5.8	9.6	11.6	16.1	19.6	12.9	12.6
Controls	7.1	10.8	12.4	15.4	19.5	6.7	10.8	12.4	17.0	20.2	13.0	13.4
WATER												
Divers	6.2	9.9	11.9	16.5	20.8	6.1	9.7	11.9	15.8	19.5	13.1	12.6**
Controls	7.2	10.9	12.0	16.3	20.4	6.9	10.5	11.9	16.8	19.8	13.3	13.2

*X̄ Pre- X̄ Post $p < .025$
**Target distance in feet in parentheses

Table A–2

Mean distance judgments for 11 divers and 15 controls.

Target Distance (feet)	PRE-TEST 3(12)*	5(18)	9(15)	12(9)	15(6)	POST-TEST 3	5	9	12	15	X̄ Pre	X̄ Post
AIR												
Divers	2.8	4.2	7.4	10.4	12.5	2.6	4.0	7.6	10.3	13.4	7.4	7.6
Controls	2.3	3.8	8.0	9.9	13.1	2.4	3.9	7.9	9.9	12.9	7.4	7.4
WATER												
Divers	2.2	3.4	6.5	9.4	10.8	2.2	3.6	6.4	9.3	11.3	6.5	6.6
Controls	2.4	3.9	7.7	11.1	13.5	2.3	4.0	7.6	10.8	12.9	7.8	7.5

*Target size in inches in parentheses

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3. REPORT TITLE

Adaptation of Divers to Distortion of Size and Distance Underwater

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (Last name, first name, initial)

Ross, Helen E., Franklin, Samuel S., Weltman, Gershon

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
January 1969	33	14

8a. CONTRACT OR GRANT NO. N00014-67-A-0111-0015 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 68-61 Biotech Lab Tech Report 45 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

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This report describes a series of five experiments conducted during summer 1968 to examine adaptation of divers to size and distance distortion underwater. Visually perceived distortions of size and distance are produced by the diver's face-mask which introduces an air-water interface between the eye and the object of regard. The effect of this interface is to decrease image distance by about one-fourth. Under these conditions objects are likely to be reported as closer or larger, or closer and larger than they actually are. Adaptation to distortions of size and distance were investigated by two techniques: 1) the method of adjustment where a diver adjusted the size of a horizontal line, set in the frontal plane at a fixed distance, to a length of 12 inches, 2) the method of estimation where the diver recorded his judgments of the size and distance of a series of targets which varied on these dimensions.

Of the five experiments conducted in the Underwater Research Facility tank and swimming pool at UCLA and in the ocean, three were successful in demonstrating adaptation.

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