

ABSOLUTE DISTANCE PERCEPTION UNDER WATER AND IMPROVEMENT
THROUGH TRAINING

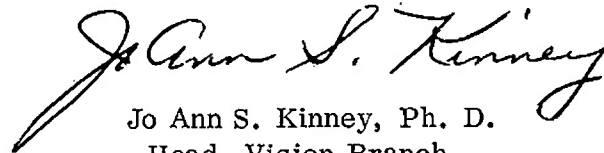
by

Steven H. Ferris, Ph. D

NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY
NAVAL SUBMARINE MEDICAL CENTER REPORT NO. 670

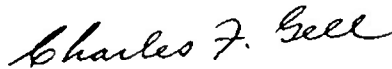
Bureau of Medicine and Surgery, Navy Department
Research Work Unit M4306.03-2050DXC5.04

Transmitted by:



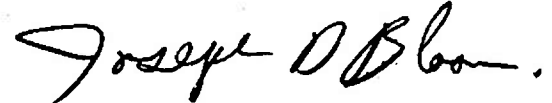
Jo Ann S. Kinney, Ph. D.
Head, Vision Branch

Reviewed and Approved by:



Charles F. Gell, M.D., D.Sc. (Med)
Scientific Director
NavSubMedRschLab

Reviewed and Approved by:



J. D. Bloom, CDR, MC, USN
Officer in Charge
NavSubMedRschLab

Approved and Released by:



J. E. Stark, CAPT, MC, USN
COMMANDING OFFICER
Naval Submarine Medical Center

Approved for public release; distribution unlimited.

SUMMARY PAGE

THE PROBLEM

To examine the nature of absolute distance estimation under water when divers make direct estimates in feet, and to determine the feasibility of training divers to compensate for their errors.

FINDINGS

Distance was under- or over-estimated, depending to a large extent on water turbidity, which increased the magnitude of judgments. Divers quickly learned to make accurate judgments when they were informed of the correct distance after each of a series of judgments. However, training did not adequately transfer to another body of water when there were large differences in turbidity.

APPLICATION

The results have implications for the training of Navy divers. Divers should be made aware of the fact that the perception of distance under water is dependent on water conditions. For tasks requiring accurate distance estimation, specific training in judging distance would be of considerable value.

ADMINISTRATIVE INFORMATION

The investigation was conducted as a part of Bureau of Medicine and Surgery Research Work Unit M4306.03-2050D, Evaluation of Sensory Aids and Training Procedures on Navy Divers' Visual Efficiency. The present report is No. 4 on that Work Unit. It was approved for publication on 28 June 1971 and designated as Submarine Medical Research Laboratory Report No. 670.

PUBLISHED BY THE NAVAL SUBMARINE MEDICAL CENTER

ABSTRACT

A series of experiments was performed to obtain direct estimates of absolute distance under water, and to determine if judgment accuracy can be improved through training. Distance was under- or over-estimated, depending to a large extent on water turbidity, which increased the magnitude of judgments. Also, whereas the power-function exponent for distance estimation in air was slightly less than 1.0, exponents in water were greater than 1.0 and increased with increased turbidity. Divers quickly learned to make accurate judgments when they were informed of the correct distance after each of a series of judgments, but training did not adequately transfer to another body of water when there were large differences in turbidity. The results have implications for the training of divers.



ABSOLUTE DISTANCE PERCEPTION UNDER WATER AND IMPROVEMENT THROUGH TRAINING

In the underwater environment, the apparent distances of objects are considerably distorted. It had traditionally been believed that distance is underestimated in water since the optical distortion due to wearing a face mask theoretically causes an object to appear closer than it really is. In practice, however, the water is often turbid, and overestimation often occurs (Luria, Kinney, & Weissman, 1967; Kinney, Luria, & Weitzman, 1969). Even in very clear water, estimates in water exceed estimates in air at large distances (Ross, 1967; Woodley & Ross, 1969). According to Kinney, et al. (1969), water turbidity causes a loss of contrast and hence greater distance estimates.

Since the inaccurate judgment of distance under water is of practical significance to SCUBA divers, one purpose of the present research was to determine if judgment accuracy can be improved through training. Training can lead to accurate judgments in air (Gibson & Bergman, 1954; Gibson, Bergman, & Purdy, 1955), but training has not been attempted in water, where errors are larger.

In the Luria, et al. (1967) and Kinney et al. (1969) experiments, the observers made distance judgments relative to a 2-ft. standard distance. Since divers normally do not have a standard distance for comparison, it was considered more appropriate in the present experiments to have subjects make direct magnitude estimates in feet. A second purpose of the current research was to determine

if this method leads to similar conclusions concerning the nature of distance perception under water.

In addition, an analytical technique used extensively with the method of magnitude estimation was applied to the present research. According to Stevens' (1957) psychophysical power law, perceptual scales are related to physical scales by power functions. If perceptual magnitude as a function of physical magnitude is plotted on log-log coordinates, the slope of the best-fitting straight line is equivalent to the exponent of the power function. Exponents have been obtained for absolute distance in air (Künnapas, 1960; 1968; Teghtsoonian & Teghtsoonian, 1969; 1970), but similar analyses have not been done for water data. Since distance perception in water apparently differs from distance perception in air, exponents were computed in the present experiments in order to gain a better understanding of the nature of these differences.

GENERAL METHOD

Subjects

A total of 119 Navy personnel (110 enlisted men and 9 officers) at the Naval Submarine Base New London served as subjects. None had any prior experience with the experimental situation. When asked to rate their degree of previous experience diving with mask and snorkel, 46 replied, "Never," 53 replied "Occasionally," and 20 replied,

"Frequently." Each subject took part in only one experiment.

Apparatus

Under water. Distance judgments were usually obtained in an outdoor, above-ground swimming pool which was 20 ft. in diameter and 4 ft. deep. Visibility through the water, which was controlled by how often the filter was used, was maintained between 8 and 15 ft. A rope marked with tape at 6 in. intervals was tied across the pool, above the water level. The stimulus object, an ordinary soda can (2-3/4 in. diameter, 4-3/4 in. high) painted fluorescent orange, was hung from the rope by heavy wire. The can hung about 8 in. below the surface, approximately at eye level. The distance of the can from the observer was varied by moving it to a new position along the rope. The rope was not visible to a submerged observer.

Each subject wore a face mask, snorkel, weight belt, and usually a rubber wet-suit. Two subjects at a time made distance judgments. Both subjects sat next to each other on cement blocks at one end of the pool. Their heads were below the rope and just below the surface, with the line of sight of each subject approximately parallel to the rope. An aluminum partition was mounted between the two subjects to prevent them from seeing each other. In order to mark the proper head position, a rod was mounted in front of the subjects, just below the surface and perpendicular to the line of sight. Between judgments, a small sheet of aluminum was placed in front of each subject so that they could not see the target being moved.

Air. The arrangement for obtaining distance judgments in air was similar to the arrangement used in water. A rope marked in 6 in. intervals was hung between two poles mounted on a flat, grass covered area next to the pool. Two subjects at a time sat at one end, separated by a wood partition. A sheet of cardboard was attached to the front of the partition, perpendicular to the line of sight. The bottom of the cardboard was just above eye level. It served to block the rope from view, and also served as a marker for head position. A soda can identical to the one used in the water was hung at eye level at various positions along the rope. A sheet of cardboard was used to block the subjects' view of the can between judgments. The subjects wore face masks, but no other equipment.

Procedure

Identical testing procedures were used in water and in air. Before testing in water, those subjects who had no previous experience with mask and snorkel were given initial instructions and practice. All subjects were informed that their task would be to judge how far away from them the test object appeared to be, to the nearest ft. or half-ft. Their judgments were indicated by how many fingers they held up above the water for water tests, or in front of them for air tests (one finger for each ft., a bent finger for a half-ft.). There were usually 10 test distances, 1 ft. through 10 ft. Each distance was presented twice, in random order. For water judgments, subjects were instructed to remain submerged during the entire testing period (about 5 min.), but they were informed that they could surface if

they became uncomfortable or if their mask became fogged.

The data obtained were analyzed in the following manner. The two distance judgments for each subject at each distance were averaged, and medians were determined for the group. Median judged distance as a function of actual distance was then plotted graphically. In cases where data for an individual was missing at the longer distances due to poor visibility, one or two procedures was used. If only one of the two judgments was missing, the one judgment obtained was also assigned to the missing judgment. If both judgments were missing, the individual's data were plotted graphically and the missing judgments were obtained by extrapolation.

In order to determine the exponent of the power function relating judged to physical distance, log judged distance was plotted as a function of log physical distance. The slope of the best fitting straight line (equivalent to the exponent of the power function) was then determined by the method of least squares. The value for 1 ft. was omitted if it deviated markedly from linearity. Analyses of variance for multifactor designs with repeated measures were used to evaluate the statistical significance of the effects of experimental variables.

Experiment I; Comparison of Air and Water Judgments

Method

Twenty-three enlisted men who were beginning a Navy SCUBA class were tested in both air and water. One group of 12 subjects was tested first in water,

and immediately afterwards, in air. The testing order was reversed for the remaining 11 subjects. All testing was done on the same day, so that water turbidity remained reasonably constant throughout the experiment. In a second experiment on another day, a similar procedure was used to test nine medical officers who were also beginning a SCUBA class. Five subjects were tested in air first, and four were tested in water first.

Results and Discussion

Enlisted men. Since testing order did not significantly affect the results ($F < 1.0$), medians for the combined data for the two groups were computed. Median judged distance as a function of actual distance is plotted for water and air in Fig. 1A. Distances in both water and air were considerably underestimated. Up until 4 ft., estimates for water were less than for air, and less than the theoretical optical distance. Beyond 6 ft., the water estimates exceeded the optical distance, and beyond 7 ft. they exceeded the air estimates. Overall, the results for water and air did not differ significantly ($F=2.87$, $df=2/21$, $p>.10$), but the Water-Air x Distance interaction was significant ($F=2.71$, $df=9/89$, $p<.01$). Individual paired comparisons (Newman-Keuls) indicated that the water and air data differed significantly at 7 ft. ($p<.05$), and at 8, 9, and 10 ft. (p 's $<.01$). Power function exponents for the water and air data, respectively were 1.26 and 0.99.

Medical Officers. Water and air distance functions for these subjects are shown in Fig. 1B. Although the Medical

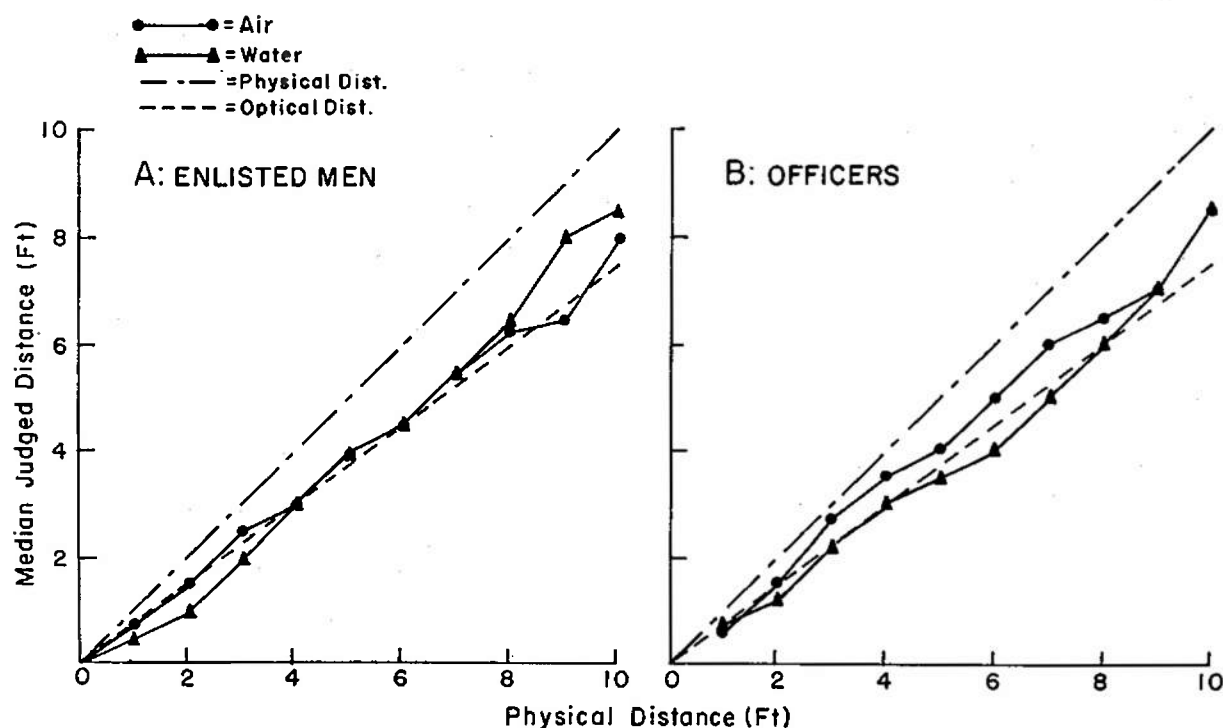


Fig. 1. Median distance estimates in air and water for the SCUBA classes of Experiment 1.

Officers underestimated to a greater extent in water, the results are basically similar to the results for the enlisted men. Distances were underestimated to a greater extent in water than in air, with water estimates generally less than the optical distance until about 8 ft. The results for water and air differed significantly ($F=6.14$, $df=1/7$, $p < .05$). The Water-Air $\times$ Distance interaction was also significant ($F=2.43$, $df=9/63$, $p < .05$), indicative of the fact that the largest differences occurred at the middle distances. Water and air exponents for the medical officers were 1.10 and 1.00, respectively. Hence for both groups, the water exponent was

greater than 1.0 and the air exponent was 1.0 or less.

Experiment 2: Improvement with Training

Method

A total of 40 subjects were randomly assigned to one of four groups, each group having 10 subjects. The procedure for each group was as follows:

Feedback: Subjects were given an initial water test (T_1), then 20 training trials, and finally a second water test (T_2). The training trials were similar to the test trials, except that the subjects were informed of the correct

distance after each judgment. The distances used in the training series included half-ft. values in order to minimize the memorization of specific distances.

Practice without feedback: Subjects of this group followed the same procedure as the Feedback group, but they were not informed of the correct distances during the training trials.

No practice: Subjects of this group received no practice trials between T_1 and T_2 . They remained under water during the 5 min. training period and were allowed to swim freely around the pool.

Checkers: Members of this group also received no practice between T_1 and T_2 . Instead of swimming during the training period, each pair of subjects played a game of checkers under water.

Results and Discussion

The median T_1 and T_2 distance estimates for the four groups are plotted in Fig. 2. Overall, the results for the four groups did not differ significantly ($F < 1$). However, the T_1 and T_2 results differed significantly ($F=8.61$, $df=1/36$, $p < .01$) and the Group $\times$ Test interaction was significant ($F=3.43$, $df=3/36$, $p < .05$). Differences between the various Group $\times$ Test combinations were analyzed by means of the Tukey (a) method (Winer, 1962).

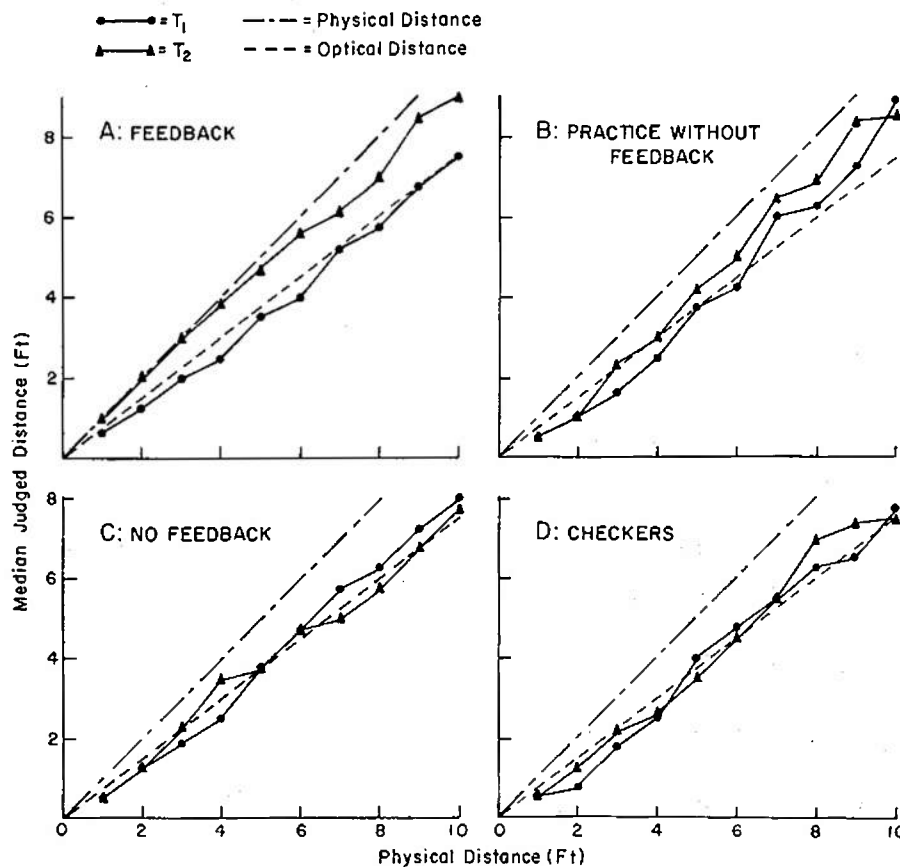


Fig. 2. Median T_1 and T_2 distance estimates in water for the four groups of Experiment 2.

Initial judgments. The T_1 estimates were similar for the four groups. In general, distance initially was underestimated, with judgments less than the optical distance at least until about 5 ft.

Effect of training. For the Feedback group, training produced a large, statistically significant improvement in judgment accuracy ($p < .01$). The T_2 estimates for the Feedback group were significantly more accurate than the T_2 estimates for each of the three other groups (p 's $< .01$). However, there was still some underestimation at the longer distances. The Practice-Without-Feedback group also showed significant improvement ($p < .01$), but significantly less improvement than the Feedback group ($p < .01$). Neither the No-Practice nor the Checkers group showed consistent improvement when retested. It is clear that a training procedure in which subjects are informed of the correct distance after each judgment is an effective method for improving judgment accuracy.

Power-function exponents. Exponents for the T_1 and T_2 data for the four groups are listed in Table I. Before training, all exponents were greater than 1.0. A plot of the combined T_1 data for all four groups has an exponent of 1.24. Training lowered the exponent considerably for the Feedback group, and at least a slight lowering also occurred for the other groups.

Effect of turbidity. Since this experiment was run over a period of several days, water clarity did not remain constant. The results discussed above were not biased by this variability because each group was about equally

Table I. Experiment 2: Power Function Exponents

Group	T_1	T_2
Feedback	1.12	0.94
No-Feedback	1.36	1.29
No-Practice	1.23	1.17
Checkers	1.28	1.20

affected. However, an additional analysis of the data was performed in order to assess the effect of water visibility on the initial distance judgments (across all groups). By examining the T_1 data for individual subjects, 11 subjects who could not see the stimulus at 8 ft. (judgments for 8, 9, and 10 ft. were not obtained) were distinguished from 18 subjects who could see the stimulus at 10 ft. (all judgments were obtained).

Medians for these two groups of subjects are plotted in Fig. 3. There was significantly greater underestimation in relatively clear water than in more turbid water ($F=15.32$, $df=1/27$, $p < .001$). The medians for the "clear" group fall below the optical distance until 8 ft., whereas the crossover point is 4 ft. for the "turbid" group. The 8, 9, and 10 ft. medians for the "turbid" group must be viewed cautiously since they are based on extrapolations for each individual. However, it would appear that underestimation no longer occurred for these subjects beyond 7 ft. The leveling off of the upward curvature after 7 ft. may be due only to the extrapolation procedure. Exponents were 1.23 and 1.33,

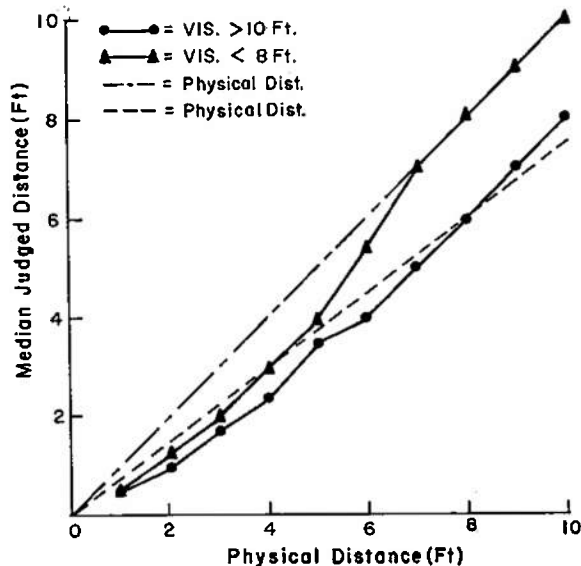


Fig. 3. Median distance estimates as a function of water turbidity (data from Experiment 2).

respectively, for the "clear" and "turbid" plots. The finding that greater turbidity led to greater distance estimates, particularly at larger distances, is consistent with previous results (Kinney, et al., 1969).

Experiment 3: Effect of Water Turbidity and Training in Air

Method

Two groups of 10 subjects were used. For one group the water was relatively clear (visibility generally > 9 ft.), whereas for the other group the water was relatively turbid (visibility generally < 8 ft.). Although the two groups were tested on separate days, the same procedure was used for each. Two subjects at a time were tested first in water (Water₁) and then in air (Air₁). They were then trained with feedback in air,

retested in air (Air₂) and finally retested in water (Water₂).

In a separate experiment, distance judgments from 15 subjects were obtained in very clear water (visibility > 60 ft.). A rope for the target was attached between the shallow and deep ends of a large, indoor swimming pool (35 x 82 ft.). The rope was above the surface, between and parallel to two racing-lane lines painted along the bottom. One subject at a time knelt at a chin rest below the surface at the shallow end (about 4 ft. deep). The test distances were 2, 3, 4, 5, 7, 9, 12, 15, 20 and 30 ft.

Results

Effect of turbidity. Median initial water and air judgments (Water₁ vs. Air₁) from the first experiment are plotted in Fig. 4A and 4B for moderately clear and turbid water. In clear water, there was greater underestimation than in air, and water judgments were less than the optical distance. In turbid water, however, estimates were greater than the optical distance after 3 ft., and greater than the air estimates after 4 ft. The exponents for the Air₁ and Water₁ distance functions are listed in Table II. For both groups, the air exponent is less than 1.0 and the water exponent is greater than 1.0. The effect of turbidity on the distance function is most clearly illustrated in Fig. 4C in which the Water₁ results for the two groups are compared. There was significantly less underestimation in turbid than in clear water ($F=23.99$, $df=1/18$, $p < .001$). The Turbidity x Distance interaction was also significant ($F=8.20$, $df=9/162$, $p < .001$), reflecting the fact that the

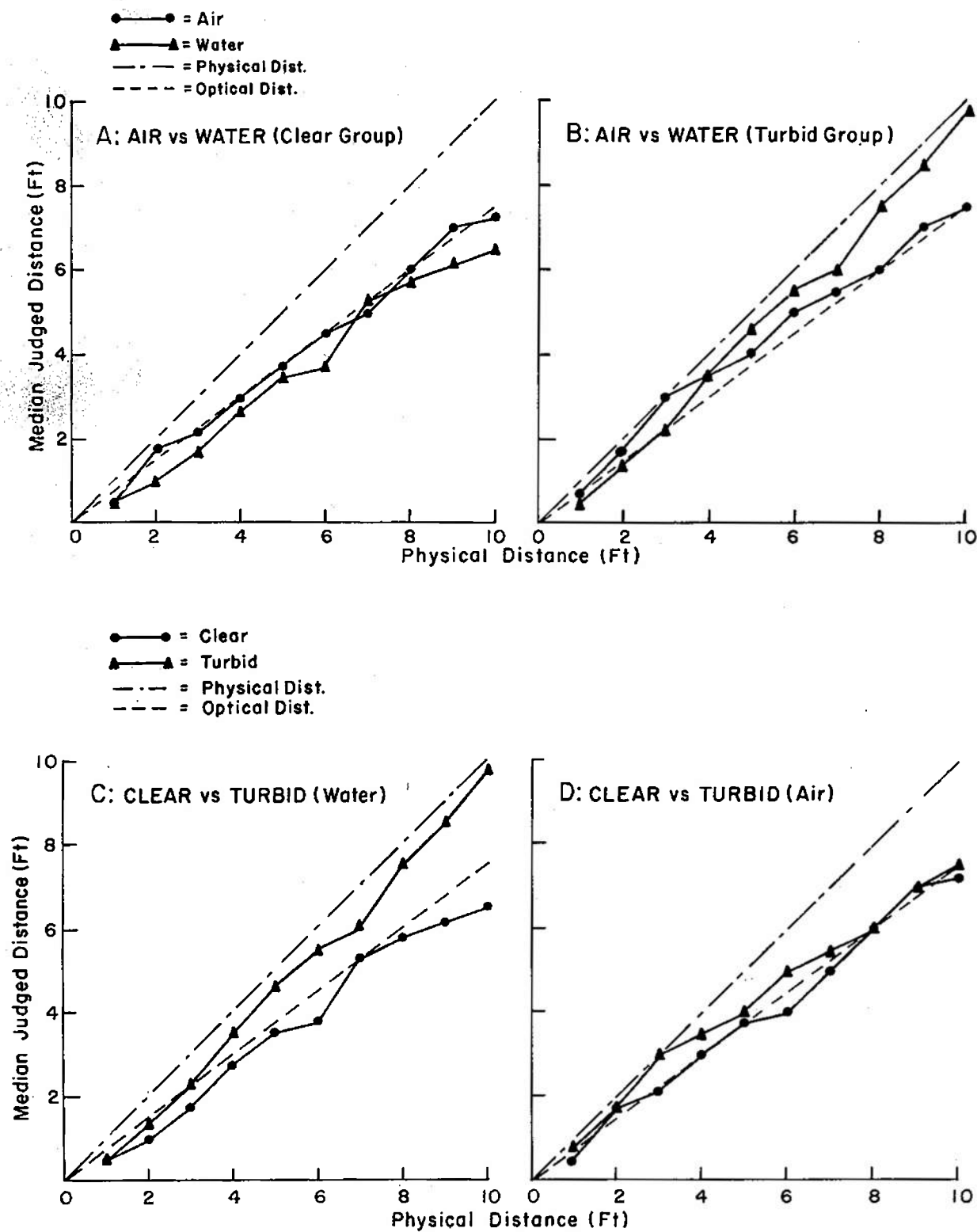


Fig. 4. Experiment 3: Median distance estimates in air and water for the Clear (A) and Turbid (B) groups; and median estimates of the Clear and Turbid groups in Water (C) and air (D).

Table II. Experiment 3: Power Function Exponents

Test	Clear Water	Turbid Water
Air ₁	0.94	0.96
Water ₁	1.16	1.26
Air ₂	0.85	0.91
Water ₂	0.95	1.05

effect of turbid water was greater at far than at near distances. Although the two turbidity groups also differed slightly in their initial air judgments (see Fig. 4D), this difference was not statistically significant ($F=2.00$, $df=1/18$, $p > .10$).

The results obtained in the very clear water of the large swimming pool are shown in Fig. 5. Estimates were less than the optical distance for all distances, and no upward trend at the large distances is apparent. The exponent is 1.03 for these data, a value considerably lower than obtained for more turbid water.

Effect of training in air. As illustrated in Figs. 6A and 6B, training in air led to significant improvement in air for both groups ($F=94.09$, $df=1/18$, $p < .001$). In water, the effect of training in air depended upon water turbidity (see Figs. 6C and 6D). For both groups, training in air significantly increased the magnitude of the water judgments ($F=32.40$, $df=1/18$, $p < .001$). The clear-water group improved considerably, and the improvement is

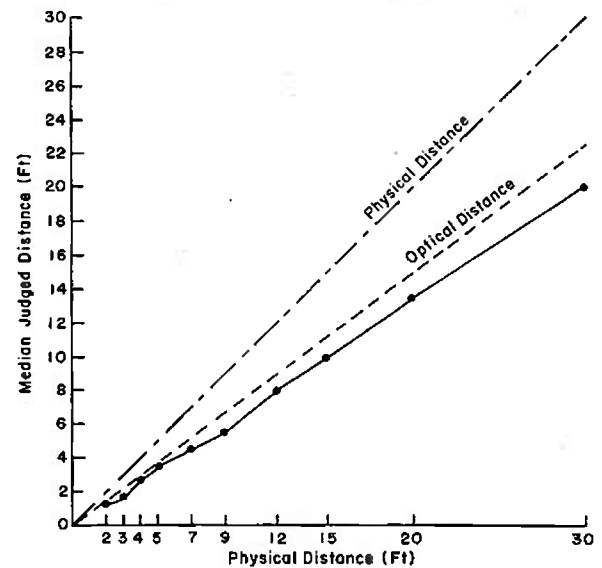


Fig. 5. Experiment 3: Median distance estimates in very clear water.

comparable to the improvement which occurred after water training in Experiment 2 (see Fig. 2A). On the other hand, the turbid-water group, which had shown only small underestimation initially, overestimated distance after training in air. For both groups, and for air as well as water, training had the general effect of lowering the value of the distance function exponent.

Discussion

The results are consistent with the principle that distance perception under water is highly dependent upon the degree of water turbidity. Relative to judgments in clear water, distance was overestimated in turbid water. This result is consistent with the results of a previous experiment (Kinney, et al.,

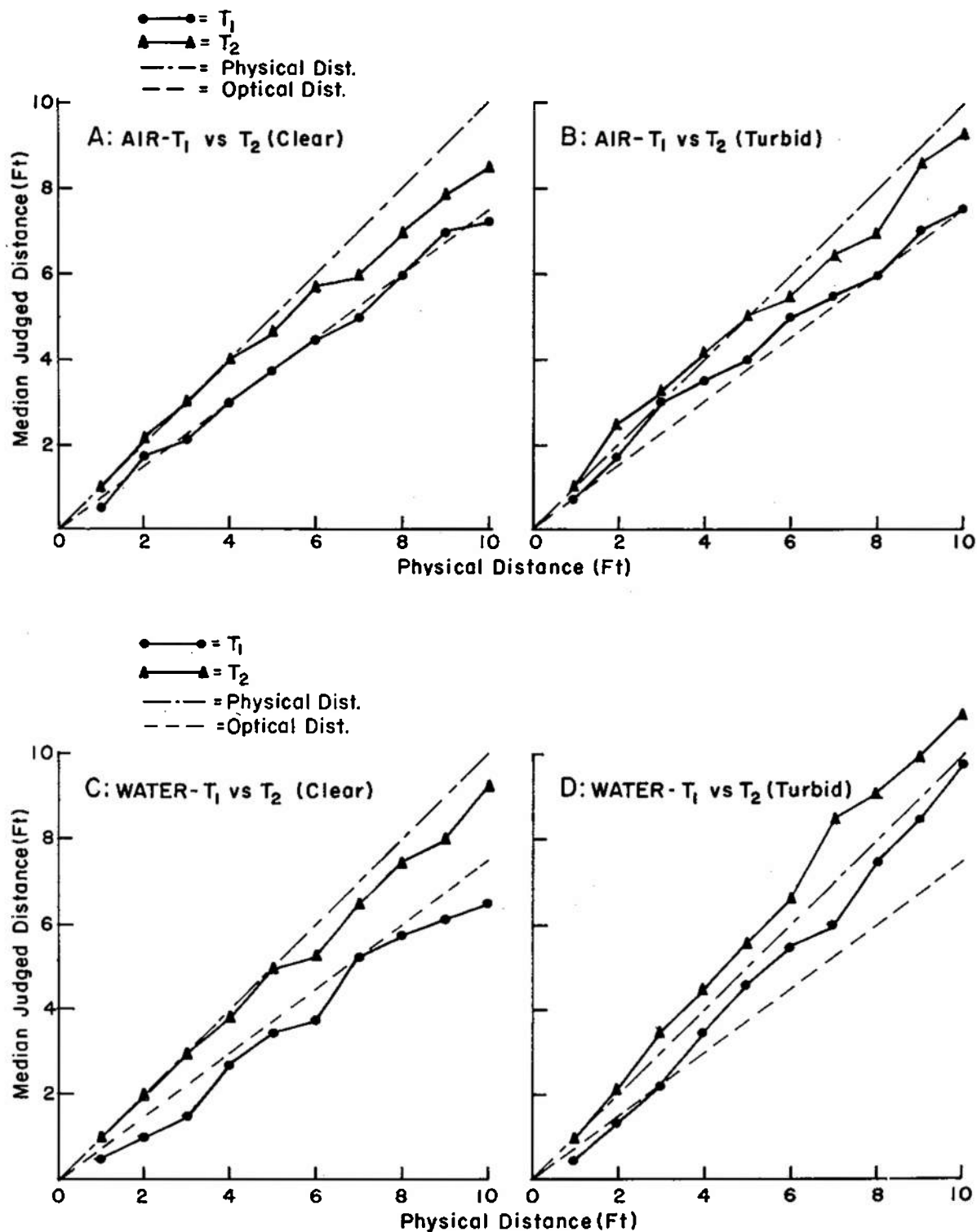


Fig. 6. Experiment 3: Effect on estimates in air (A and B) and in water (B and C) of training the Clear and Turbid groups in air.

1969), and also with the turbidity analysis of Experiment 2. Furthermore, the results confirm the fact that the distance function exponent is greater in turbid than in clear water. Thus, with increase in turbidity, there is a greater rate of increase in apparent distance with increase in physical distance. This means that as turbidity is increased, the physical distances at which the water function exceeds the optical distance and exceeds the air function move closer to the observer.

The values of the exponents obtained for air and water are comparable to the exponents obtained in the first two experiments. In air the exponent is usually less than 1.0, whereas in water the value is greater than 1.0. Hence there is a basic difference in curvature between the air and water distance functions. Training tends to lower the exponent for both air and water.

The results also demonstrate that training in air will improve judgment accuracy in water if the water is not too turbid. Improvement in water probably occurs because similar errors (underestimation) occur in both air and clear water. However, since air training is detrimental to performance in turbid water, the practical value of air training for improving underwater performance is quite limited.

Experiment 4: Effect of Turbidity on Transfer of Training

Method

Twelve subjects took part in a six phase experiment. Subjects were first tested (T_1), trained, and retested (T_2) in the usual experimental pool. The water in this pool was of "moderate"

clarity (visibility > 9 ft.). After this initial training, each subject was tested in two additional bodies of water. Six subjects were taken first to a small, turbid lake (visibility < 8 ft.), and then to a very clear, private swimming pool (30 ft. x 50 ft., visibility > 30 ft.). The remaining six subjects were taken first to the clear pool and then to the turbid lake. The subjects were tested individually, instead of in pairs (no partition was used), at each new body of water. After these two additional tests, the subjects were returned to the original training pool (moderate clarity) where they were given a final test (T_3). About 10 min. of travel time elapsed between each of the last four tests (T_2 , clear pool, turbid lake, and T_3), and about 1 hour, overall, elapsed between T_2 and T_3 .

Results and Discussion

Since the order of testing (clear pool before turbid lake or vice versa) did not significantly affect the results ($F=2.52$, $df=1/10$, $p > .10$), the combined data for the two order groups are plotted in Figs. 7A and 7B. The results for the five tests differed significantly ($F=44.51$, $df=4/40$, $p < .001$). In addition, there was a significant Test x Distance interaction, representing the fact that the results for the various tests differed to a greater extent at the larger distances. Individual comparisons among pairs of tests indicated that the results for each test differed significantly from the results for all other tests (Tukey (a) method, p 's $< .01$).

Effectiveness of Training. Median distance estimates for T_1 , T_2 , and T_3 (data obtained at the training pool) are

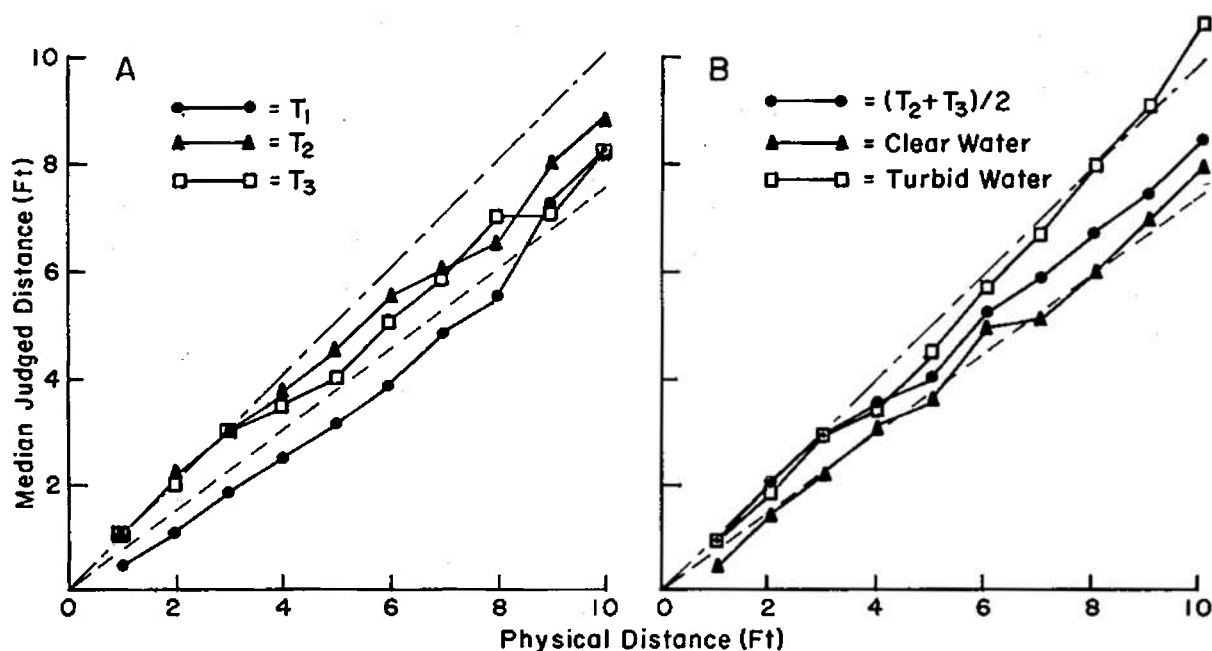


Fig. 7. Median distance estimates of Experiment 4: Effect of training (A) and differences in turbidity (B).

plotted in Fig. 7A. Comparison of the results for T_1 and T_2 indicates that considerable improvement occurred. Comparison of the T_2 and T_3 results indicates that a slight loss of improvement occurred, particularly at the longer distances, during the hour elapsing between the two tests. Power function exponents for T_1 , T_2 , and T_3 , respectively, were 1.19, 0.91, and 0.89. The lower exponents after training are consistent with previous results.

Transfer of Training. Fig. 7B illustrates the degree to which training transferred to water differing from the training water in turbidity. Since there was some loss of improvement over

time, the T_2 and T_3 medians were averaged for comparison with the data for clear and turbid water. In clear water there was consistently greater underestimation, whereas in turbid water there was considerably less underestimation at distances beyond 4 ft. Hence, after training in moderate water, estimates were less accurate in clear water and more accurate in turbid water. Power function exponents for clear and turbid water, respectively, were 0.95 and 1.06. The higher exponent for turbid water is consistent with previous results.

The results indicate that the practical value of training in a particular body of

water may be limited. Differences in water turbidity critically affect the ability of improvement to transfer to a new body of water. Although the conditions of the present experiment were such that performance was actually better in turbid water than in the moderately clear training water, it is likely that considerable overestimation would occur in turbid water if the training water were very clear. Therefore, a single training session in a particular body of water is not sufficient to improve performance in a variety of underwater conditions.

Experiment 5: Distance Judgments and Diving Experience

Method

Two procedures were used to assess the influence of diving experience on distance estimation. Members of the first SCUBA class of Experiment 1 had been tested in water and in air at the start of their course. Six members of this class were now retested in water and air at the conclusion of the course. Their new judgments (T_2) were compared to their initial judgments (T_1).

The second procedure involved a combined analysis of the water data from Experiments 1-4. As previously mentioned, all subjects were categorized as having either no previous experience with a mask and snorkel, occasional experience, or frequent experience. The initial water data for 38 subjects having no previous experience and 19 subjects having frequent experience were now compared. The data for the 25 subjects in the Turbid Water and Very Clear Water groups of Experiment 3 (8 "Never", 16 "Occasionally" and 1 "Frequent"), were excluded.

Results

Median T_1 and T_2 judgments in water and air for the retested SCUBA class subjects are plotted in Figs. 8A and 8B. Some improvement occurred in water, and a smaller amount of improvement occurred in air. T_1 and T_2 exponents were 1.23 and 1.07 for the water data, and 1.06 and 0.97 for the air data. The improvement in air may account to some extent for the improvement in water. On the other hand, inspection of the individual data suggests that the water was slightly more turbid for T_1 than for T_2 . This difference would tend to decrease any improvement on T_2 .

In Fig. 9, the medians for the subjects having no previous experience are compared to the medians for the subjects having frequent experience. Although the difference between the two groups is small and only marginally significant ($F=2.85$, $df=1/55$, $p < .10$), the "frequent" subjects were consistently more accurate in their estimates. Exponents for the two groups, in order of increasing experience, were 1.21 and 1.18.

Discussion

The results suggest that without direct training, diving experience may produce some improvement in the accuracy of absolute distance estimation. The amount of improvement which occurred was small in comparison to the improvement resulting from direct training. It is possible that the small improvement is due to visual adaptation to distance distortion. Adaptation under water has been demonstrated for hand-eye coordination (Kinney, McKay, Luria,

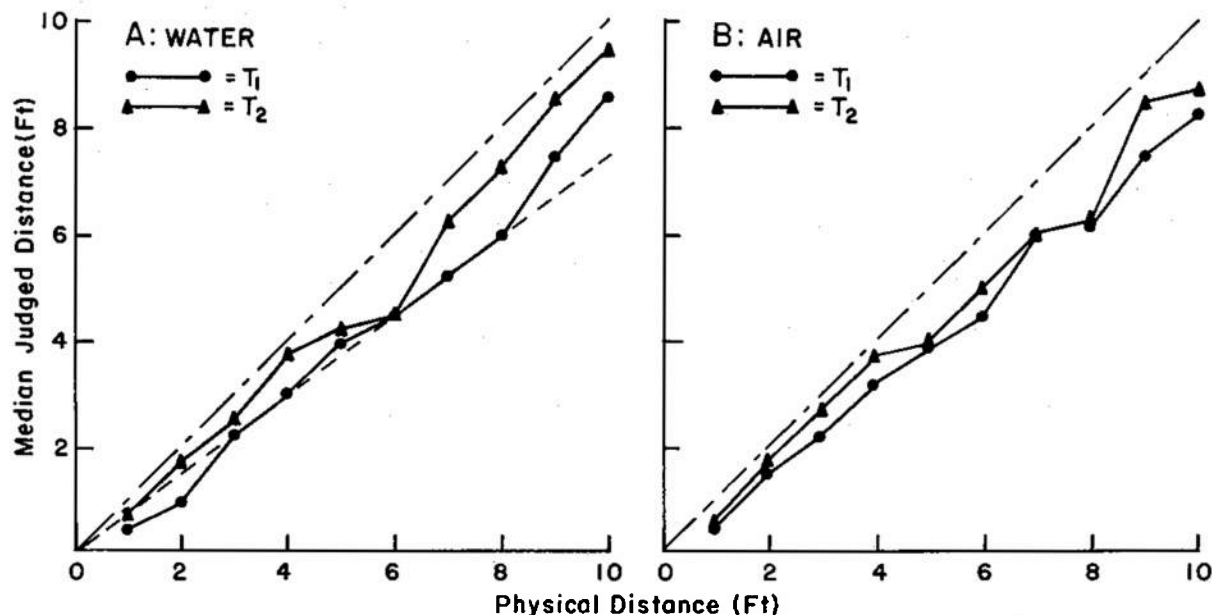


Fig. 8. Retested members of the SCUBA class: Median estimates in water (A) and air (B).

& Gratto, 1970), and Franklin, Ross, and Weltman (1970) claim to have demonstrated adaptation for absolute distance. The occurrence of absolute distance adaptation must be further substantiated, however.

GENERAL DISCUSSION

The nature of distance perception under water may be illustrated by means of the idealized distance functions of Fig. 10. To begin with, there is apparently a general tendency to underestimate distance when direct estimates in feet are made. Thus judgments in air, in the absence of optical distortion, are underestimates of the

physical distance. For our conditions, the distance function in air has a power function exponent of slightly less than 1.0, a result consistent with the findings of Teghtsoonian and Teghtsoonian (1970).

When the observer is under water and wears a face mask, two factors, optical distortion and water turbidity, must be considered in addition to the tendency to underestimate. Optical distortion causes the object to appear nearer than the physical distance. On the other hand, water turbidity produces a loss of brightness and contrast, causing the object to appear farther away. The effect of turbidity increases with distance.

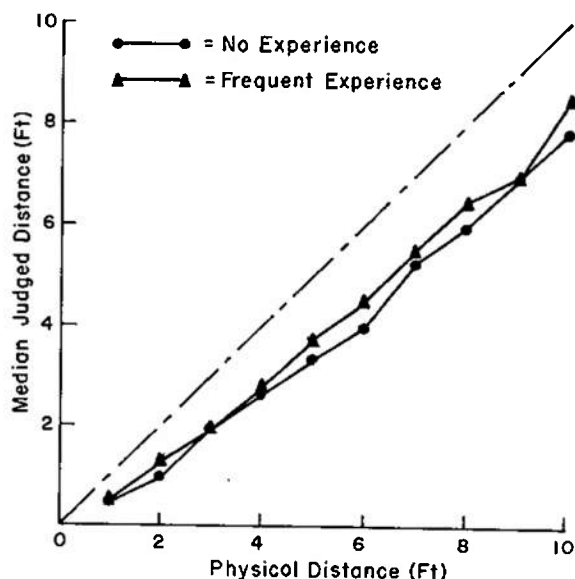


Fig. 9. Effect of previous diving experience on median distance estimates.

The interaction of optical distortion with varying degrees of turbidity, combined with the general tendency to underestimate, produces the three water curves of Fig. 10. If the water is quite turbid, estimates are less than the physical distance only at very near distances. In this near range, optical distortion combined with the underestimation tendency produces considerable underestimation. However, due to the increasing effects of turbidity with increasing distance, estimates soon exceed the optical distance, the air

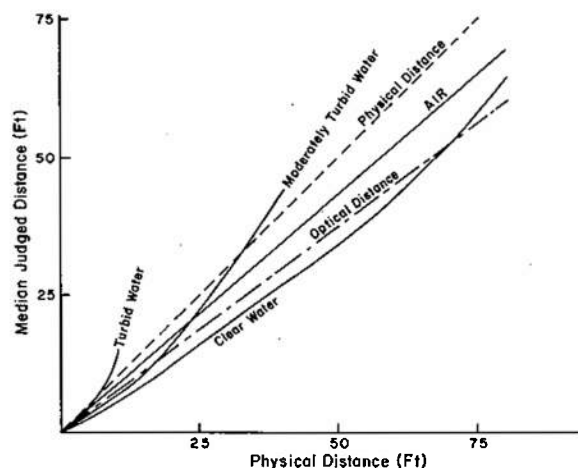


Fig. 10. Idealized functions for perception of absolute distance in air, and in turbid, moderately turbid, and clear water.

estimates, and finally the physical distance. For our turbid conditions, the distance function exponent is about 1.3 or higher.

In moderately turbid water, the distances at which estimates exceed the optical, air, and physical distance values are more distant from the observer. An exponent of about 1.2 is common for water of moderate turbidity. The curve for very clear water is tentative, since we have not collected data for such long distances. However, the function shown is consistent with data collected by Ross (1967). In very clear water, distance is apparently still underestimated at quite far distances, and the exponent approaches 1.0.

The curves of Fig. 9 indicate that divers will rarely estimate absolute

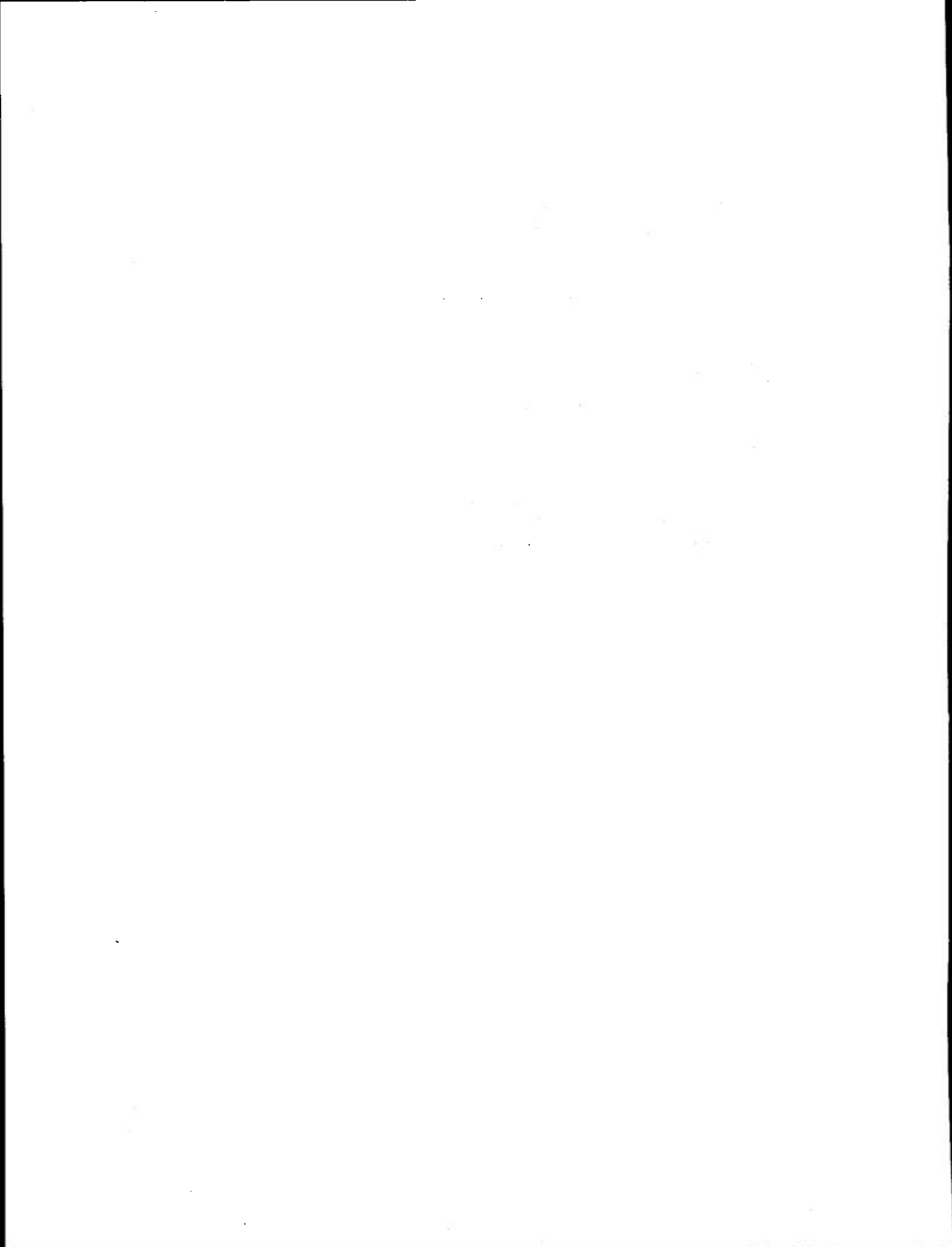
distance correctly. However, our experiments have shown that divers can easily be trained to make very accurate judgments. If observers are informed of the correct distance after each of a series of judgments, they learn to compensate for their errors. We obtained good results with only 20 training trials, and better results could no doubt be obtained with more extensive training. However, there is apparently a serious limitation to training in a particular body of water. Since turbidity influences the nature and magnitude of the original errors, it also determines the nature and magnitude of the corrections for these errors. As a result, training in one body of water may be inappropriate for another body of water if the two waters differ significantly in turbidity.

A possible solution to the transfer of training problem would be to train divers in several bodies of water so that they could learn to tailor their corrections to the prevailing conditions. The feasibility of this solution should be tested experimentally. Two other questions also require further examination: How much training is required to make the learning permanent? Is there really any true adaptation to distortion in absolute distance for distances beyond the reaching range?

REFERENCES

- Franklin, S. S., Ross, H. E., and Weltman, G. Size-distance invariance in perceptual adaptation. Psychonomic Science, 1970, 21, 229-231.
- Gibson, E. J. and Bergman, R. The effect of training on absolute estimation of distance over the ground. J. Expl. Psychol., 1954, 48, 473-482.
- Gibson, E. J., Bergman, R., and Purdy, J. The effect of prior training with a scale of distance on absolute and relative judgments of distance over ground. J. Expl Psychol., 1955, 50, 97-105.
- Kinney, J. A. S., Luria, S. M., and Weitzman, D. O. Effect of turbidity on judgments of distance underwater. Perceptual and Motor Skills, 1969, 28, 331-333.
- Kinney, J. A. S., McKay, C. L., Luria, S. M., and Gratto, C. L. The improvement of divers' compensation for underwater distortions. Naval Submarine Medical Center, Groton, Conn.: Naval Submarine Medical Research Laboratory Rep. No. 633, 1970.
- Künnapas, T. Scales for subjective distance. Scand. J. Psychol., 1960, 1, 187-192.
- Künnapas, T. Distance perception as a function of available visual cues. J. Expl. Psychol., 1968, 77, 523-529.
- Luria, S. M., Kinney, J. A. S., and Weissman, S. Estimates of size and distance underwater. Am. J. Psychol., 1967, 80, 282-286.
- Ross, H. E. Water, Fog and the size-distance invariance hypothesis. Brit. J. Psychol. 1967, 58, 301-313.

- Stevens, S. S. On the psychophysical law. Psychol. Rev., 1957, 64, 153-181.
- Teghtsoonian, M. and Teghtsoonian, R. Scaling apparent distance in natural indoor settings. Psychonomic Science, 1969, 16, 281-283.
- Teghtsoonian, R. and Teghtsoonian, M. Scaling apparent distance in a natural outdoor setting. Psychonomic Science, 1970, 21, 215-216.
- Winer, B. J. Statistical Principles in Experimental Design. New York: McGraw-Hill, 1962.
- Woodley, J. D. and Ross, H. E. Distance estimates of familiar objects underwater. Underwater Assoc. Report, 1969, 4, 58-61.



UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY (Corporate author) Naval Submarine Medical Center Naval Submarine Medical Research Laboratory		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b. GROUP
3. REPORT TITLE (U) ABSOLUTE DISTANCE PERCEPTION UNDER WATER AND IMPROVEMENT THROUGH TRAINING		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) Interim report		
5. AUTHOR(S) (First name, middle initial, last name) Steven H. Ferris		
6. REPORT DATE 28 June 1971	7a. TOTAL NO. OF PAGES 17	7b. NO. OF REFS 14
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) NSMRL Report Number 670	
b. PROJECT NO. M4306.03-2050DXC5.04		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		
10. DISTRIBUTION STATEMENT Approved for public release; distribution unlimited.		
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Naval Submarine Medical Center Box 600, Naval Submarine Base Groton, Connecticut 06340
13. ABSTRACT A series of experiments were performed to obtain direct estimates of absolute distance under water, and to determine if judgment accuracy can be improved through training. Distance was under- or overestimated, depending to a large extent on water turbidity, which increased the magnitude of judgments. Also, whereas the power-function exponent for distance estimation in air was slightly less than 1.0, exponents in water were greater than 1.0 and increased with increased turbidity. Divers quickly learned to make accurate judgments when they were informed of the correct distance after each of a series of judgments, but training did not adequately transfer to another body of water when there were large differences in turbidity. The results have implications for the training of divers.		

DD FORM 1 NOV 65 1473

(PAGE 1)

S/N 0102-014-6600

UNCLASSIFIED

Security Classification

Security Classification

DD FORM 1473 (BACK)
(PAGE 2)

Security Classification