

**This dissertation has been  
microfilmed exactly as received**

**70-9977**

**O'REILLY, Joseph Patrick, 1941-  
ADAPTATION TO VISUAL DISPLACEMENT  
THROUGH A WATER-AIR INTERFACE.**

**University of Hawaii, Ph.D., 1969  
Psychology, experimental**

**University Microfilms, Inc., Ann Arbor, Michigan**

ADAPTATION TO VISUAL DISPLACEMENT  
THROUGH A WATER-AIR INTERFACE

A DISSERTATION SUBMITTED TO THE GRADUATE DIVISION  
OF THE UNIVERSITY OF HAWAII IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN PSYCHOLOGY

SEPTEMBER 1969

BY

JOSEPH PATRICK O'REILLY

DISSERTATION COMMITTEE:

HILDE GROTH, CHAIRMAN  
HERBERT B. WEAVER  
GEORGE Y. FUJITA  
TERENCE A. ROGERS  
TERENCE O. MOORE

## ABSTRACT

Previous research on the accuracy of distance estimation of targets viewed through a water-glass-air interface (such as through a diver's facemask) has been inconsistent with effects predicted from optical principles involved. Emphasis was on the amount and types of adaptation occurring after adjusting for the effects of distortion at close (arm's reach) distances.

The recoding of sensory processing systems underlying adaptive performance was investigated with reference to existing prismatic distortion results. Distance estimation was utilized as the dependent measure, with consideration given to the function of oculomotor cues from accommodation and convergence. Reference was made to Festinger's theory of efferent readiness by stressing learning of efferent response sets activated by afferent visual input.

The effects of different forms of sensory recoding after prolonged exposure to distorted visual input was investigated, with 18 experienced and 18 novice divers performing eye-hand coordination tasks during an adaptation (warm-up) and an experimental session. During the former period, 24 minutes underwater, Ss practiced reaching tasks requiring ballistic movement while minimizing visually guided responding. Experimental tasks administered during the last 12 minutes underwater differed on the amount of conflict with the distorted visual input. After-effect measurements were taken in air after 12, 24, 30 and 36 minutes, on reaching responses to targets placed 7 and 14 inches

from the S. Measures of accuracy were supplied by both working and non-working hands. Accuracy of distance estimating while underwater was tested at the end of 0, 12, 24 and 36 minutes of practice in the distorted environment; with Ss matching targets set at 6, 12 and 18 inches. Only working hand responses were collected for the underwater testings.

Comparison of working and non-working hand responses on the after-effect measurements provided an indication of visual vs. proprioceptive adaptation. Results showed that experienced divers adapted with both working and non-working hands. Novice divers exhibited adaptation only with their working hand during the adaptation session, but showed some evidence of non-working hand adaptation during the experimental phase. Initially, working hand responses did not differ for the two experience groups, while experienced divers demonstrated significantly more adaptation with their non-working hand than did the novices. Experienced divers significantly increased adaptive responding with working and non-working hands over time, while novice performance did not change after the second 12 minute practice session. The results were taken as evidence of visual adaptation by Ss experienced in performing in the distorted environment, and proprioceptive adaptation for inexperienced Ss.

Adaptation over time was apparent from underwater distance estimation results. Increased underestimation from air pretests occurred as the target placement distance increased. Novices exhibited significantly greater loss in accuracy on initial underwater measurements, gradually reaching the level of proficiency of the more

experienced divers. Neither group demonstrated perfect adaptation during the 36 minutes of underwater testing for the 12 and 18 inch distances, although adaptation was complete for the closer (6 inch) placement.

Interpretations for increased adaptation at closer distances were presented. Rationale were provided to integrate existing reports of distance overestimation with underestimation of distance found in the present investigation, and that predicted by optical principles. Further experiments designed to clarify the controversy between visual and proprioceptive restructuring were suggested.

## TABLE OF CONTENTS

ABSTRACT. . . . .	ii
LIST OF TABLES. . . . .	vi
LIST OF ILLUSTRATIONS . . . . .	ix
CHAPTER I. INTRODUCTION	
Visual Performance Studies of Divers. . . . .	1
Distance Perception Underwater. . . . .	5
Physical Principles Underlying Water-Air Distance Distortion . . . . .	8
Adaptation to Distance Distortion of Targets Within Reaching Distance . . . . .	13
Adaptation to Visually Distorted Input. . . . .	18
Visual or Proprioceptive Adaptation - An Area of Conflict . . . . .	22
Inducing Visual Adaptation. . . . .	26
Conditional Adaptation. . . . .	28
An Approach to Understanding Adaptation to Underwater Distortion . . . . .	30
Summary and Hypotheses. . . . .	36
CHAPTER II. METHOD	
Selection of Subjects . . . . .	38
After-effect Testing Device . . . . .	41
SLIDE Apparatus . . . . .	44
Adaptation Tasks. . . . .	46
Experimental Tasks. . . . .	48
Procedure . . . . .	50
Experimental Design . . . . .	53
CHAPTER III. RESULTS	
After-effect Analysis . . . . .	55
Adaptation Period . . . . .	56
Experimental Period . . . . .	65
Adaptation Period Task Analysis . . . . .	74
Experimental Period Task Analysis . . . . .	76
After-effect Magnitude Related to Target Distance . . . . .	76
SLIDE Analysis. . . . .	76
CHAPTER IV. DISCUSSION. . . . .	90
CHAPTER V. CONCLUSIONS . . . . .	107
REFERENCES. . . . .	112

## LIST OF TABLES

Table 1.	Schematic of Experimental Design Time Sequence of Task and Test Administrations For After-effect and SLIDE Testing . . . . .	54
Table 2.	t-Test Comparisons of Target Distance Using Adaptation Session Difference Scores By Experience Groups . . . . .	57
Table 3.	t-Test Comparisons of Target Distance Using Experimental Session Difference Scores By Experience and Feedback Groups . . . . .	58
Table 4.	Summary of Analysis of Variance on Adaptation Period Difference Scores Experience X Hand X Time . . . . .	60
Table 5.	Summary of Analysis of Variance on Adaptation Period Difference Scores Feedback Group X Hand X Time Experienced Subjects . . . . .	61
Table 6.	Summary of Analysis of Variance on Adaptation Period Difference Scores Feedback Group X Hand X Time Novice Subjects. . . . .	62
Table 7.	Summary of t-Tests Between Adaptation Period Scores and Pretest By Experience Groups. . . . .	64
Table 8.	Summary of Analysis of Variance on Experimental Period Difference Scores Experience X Hand X Time . . . . .	69
Table 9.	Summary of Analysis of Variance on Experimental Period Difference Scores Feedback Group X Hand X Time Experienced Subjects . . . . .	70
Table 10.	Summary of Analysis of Variance on Experimental Period Difference Scores Feedback Group X Hand X Time Novice Subjects. . . . .	71

Table 11.	Summary of t-Tests Between Experimental Scores and Adaptation Level at End of 24 Minutes U/W By Experience and Feedback Groups. . . . .	73
Table 12.	Mean Changes in Apparent Distance For Adaptation Tasks By Experience Group and Hand . . . . .	75
Table 13.	Mean Changes in Apparent Distance For Experimental Tasks By Experience Group, Feedback Condition, and Hand . . . . .	77
Table 14A.	Analysis of Variance Summary Table for SLIDE Experienced Subjects on 6" Target Placement . . . . .	80
Table 14B.	Newman-Keuls Range Statistic Mean Scores for Experienced Subjects on 6" Target Placement. . . . .	80
Table 15A.	Analysis of Variance Summary Table for SLIDE Novice Subjects on 6" Target Placement . . . . .	81
Table 15B.	Newman-Keuls Range Statistic Mean Scores for Novice Subjects on 6" Target Placement . . . . .	81
Table 16A.	Analysis of Variance Summary Table for SLIDE Experienced Subjects on 12" Target Placement . . . . .	83
Table 16B.	Newman-Keuls Range Statistic Mean Scores for Experienced Subjects on 12" Target Placement. . . . .	83
Table 17A.	Analysis of Variance Summary Table for SLIDE Novice Subjects on 12" Target Placement. . . . .	84
Table 17B.	Newman-Keuls Range Statistic Mean Scores for Novice Subjects on 12" Target Placement. . . . .	84
Table 18A.	Analysis of Variance Summary Table for SLIDE Experienced Subjects on 18" Target Placement . . . . .	85
Table 18B.	Newman-Keuls Range Statistic Mean Scores for Experienced Subjects on 18" Target Placement . . . . .	85

Table 19A.	Analysis of Variance Summary Table for SLIDE Novice Subjects on 18" Target Placement. . . . .	86
Table 19B.	Newman-Keuls Range Statistic Mean Scores for Novice Subjects on 18" Target Placement . . . . .	86
Table 20.	Summary of t Comparisons for Experienced and Novice Group Means on U/W Pretest Difference Scores from A/W Pretest . . . . .	88

## LIST OF ILLUSTRATIONS

Figure 1.	Visual Angles and Retinal Images Under Two Viewing Conditions. . . . .	10
Figure 2.	Convergence of the Eyes Under Two Viewing Conditions. . . . .	12
Figure 3.	Accommodation of the Lens Under Two Viewing Conditions. . . . .	14
Figure 4.	Schematic Drawing of the After-effect Testing Device (A-ETD). . . . .	42
Figure 5.	Schematic Drawing of SLIDE Apparatus. . . . .	45
Figure 6.	Comparison of Amount of Adaptation By Working and Non-Working Hands for Experienced and Novice <u>Ss</u> During Adaptation Phase. . . . .	59
Figure 7.	Comparison of Change in After-effect By Working and Non-Working Hands Hi and Lo Feedback Subjects Experienced Group . . . . .	66
Figure 8.	Comparison of Change in After-effect By Working and Non-Working Hands Hi and Lo Feedback Subjects Novice Group. . . . .	67
Figure 9.	Distance Estimations From SLIDE Apparatus . . . . .	79
Figure 10.	Relationship Between Apparent Distance and Position of Interface . . . . .	103
Figure 11.	Comparison of Apparent and Actual Distances on Above-Water Measurements From Three Studies. . . . .	106

## CHAPTER I

One major emphasis in contemporary industrial research is directed toward determining the feasibility of humans dwelling and laboring in an underwater environment for extended periods of time. Undersea habitats have been developed to prolong the time a diver may function underwater by effectively reducing time required for decompression per hour of work. The Conshelf, Sealab, Man-in-Sea, and Tektite investigations have demonstrated that man can survive and function while submerged for long periods under the sea.

It is recognized that as divers pass in and out through an interface between the water and the artificial atmosphere of their habitat they are exposed to two vastly different environments. The perceptual effects of frequent changes between the heavier density water and the lighter air atmosphere apparently have not received extensive investigation. In particular, the degree to which the visual input is perceptually distorted, and the amount and type of adaptation that occurs to this distorted input have not been adequately determined. The present research purports to investigate the ability of novices and experienced divers to adapt to distance distortions experienced in viewing through a facemask while underwater.

### Visual Performance Studies of Divers

Of the available literature on underwater vision several have been concerned with defining and improving the visual field of the diver (Weltman, Christianson, and Egstrom, 1965; Barnard, 1961; Faust and

Beckman, 1966), and testing the limitations of contact lens and other corrective lens devices (Faust and Beckamm, 1966; Newton, 1967).

Weltman and Egstrom (1966) have investigated the perceptual narrowing of a diver's visual field with a vigilance task and concluded there is some restriction of the perceptual field - most probably due to perceived stress.

Studies of visibility of colors underwater, and adaptation to the homogeneous color fields experienced while diving have been reported by Kinney and co-workers (Kinney, Luria, and Weitzman, 1967, 1968b; Kinney and Cooper, 1967). The latter laboratory study verified subjective reports of color adaptation in divers, where the normal blue-green background of the sea appears colorless and normally neutral colors take on various yellow-red hues. Kinney and Cooper (1967) found that sizable changes in the phenomenal appearance of colors appeared within five minutes of exposure to homochromatic visual worlds designed to simulate the fields experienced by divers. The authors interpret this as a shift in color perception of the diver as he adapts to a blue-green visual world. As will be noted, the ability of an individual to adapt to changes in visual stimulation has been heavily documented. Kinney and Cooper provide evidence of one type of human plasticity toward distorted sensory input.

Visual acuity underwater has also been a frequent area of investigation. Since further discussion of visual-motor performance underwater will be directly related to changes in acuity of the diver, a brief synopsis of the literature appears justified. There appears to be general agreement that visual acuity does not necessarily suffer

underwater. Kent (1966) found that minimum separable acuity with Landolt ring targets was improved underwater relative to air. Faust and Beckman (1966) corroborated these results by measuring performance on standard Snellen charts. They reported increased visual acuity underwater with standard (uncorrected) facemasks, and an even greater increase in acuity with corrected air-water lenses. These results are probably due to the increased apparent size of the object in water. Christianson (1968) also found that visual resolution of divers did not significantly change in water when image magnification was controlled by matching virtual images. The author concluded that a diver in clear water can resolve an adequately illuminated target with at least as good an accuracy as he can in air, although the time required to perceive and respond to the presentation of a target significantly increased when the diver was in water rather than air.

However, Baddeley (cited in Ross, 1967a) found no improvement in performance at an acuity task conducted in the ocean, even at very near distances. It is significant to note that this latter study was the only one conducted in the open ocean. Possible introduction of factors such as decreased illumination due to depth and murkiness of the water, stress and cold could account for Baddeley's results.

Ross (1967a) measured stereoscopic acuity thresholds in the open ocean for good-acuity and poor-acuity divers and found that stereoacuity is reduced underwater, particularly for low-visibility water, because of lower illumination and brightness contrast. While stereoacuity is theoretically independent of viewing distance on land, when measured in angular terms, it should deteriorate with distance in

water due to decreased brightness contrast. This effect was found for poor-acuity divers but not for good-acuity divers. Ross reports that for typical ocean testings stereoacuity can be reduced by a factor of at least 3, with the resolution increasing for greater depths or murkier water.

In comparing stereoacuity for targets in air and in water of varying clarity, other investigators have corroborated Ross's results; reporting a decrease in stereoacuity in water deteriorating as the clarity of the water decreased (Luria, 1968a; Luria and Kinney, 1968b). The authors also found that stereoacuity decreased in air when there was a loss of peripheral cues. In a related above water study Kinney (1968) measured resolution acuity and stereoacuity with visual fields of varying size. Resolution acuity showed no marked changes, while stereoacuity was progressively reduced as the field of view as constricted (Luria, 1968b), suggesting that the reduction in visual stimuli available to the diver underwater should account for some of the noted loss in stereoacuity.

While loss of stereoacuity can severely restrict the accuracy of distance and depth perception, in a fresh water pool with high visibility the phenomenon should be effective only at great distances. In a shallow clear pool resolution acuity should be enhanced, and stereoacuity should not be restricted to any appreciable degree for targets placed within arm's reach of the subject, since this latter effect appears due to lower illumination and contrast, particularly for viewing distances around 40 feet.

### Distance Perception Underwater

Only a few investigations have been reported attempting to define the extent of observed size and distance changes underwater. On a questionnaire administered to 100 professional Navy divers, Kent (1966) found that 50 percent of the expert divers thought objects looked clearer underwater than above, 39 percent reported no difference in clarity in air or in water. Among the 78 percent who felt that depth perception was different underwater, 94 percent reported objects looking closer in water than in air, while six percent reported the reverse. The recently published investigations into distance judgments underwater have tended to disagree with the subjective reports of the Navy divers.

Ross (1965a) has reported a measure of size-constancy of divers. She noted that measured constancy ratios were greater in clear water than on land. As was expected from the physical principles underlying underwater visual distortion, Ross found a decrease in reported apparent distance in clear water, but increases in apparent distances in murky water. The author attributes the former effect to refraction; the latter effect is attributed to distance cues available from particles suspended in the water. In a similar article Ross (1965b, 1968) reported that size underwater was greatly overestimated, with marked variability due to the target distance. Similar above water measurements were slightly underestimated, but showed little change with observation distance. In measuring distance estimations, Ross found that estimations made in air and in water were both greatly underestimated for targets placed from 15 to 75 feet from the subject,

actually registering below the  $3/4$  optical distance expected in water. The underwater estimates were less than the air estimates at near distances, but beyond 40 feet they were markedly greater. The author attributes this relative overestimation at far distances to be due to a loss of contrast between the object and its background. Ross (1967b) reported an additional study where the distance estimates underwater for targets placed from 15 to 60 feet were always greater than the  $3/4$  land distance, or optical distance in water. As in her earlier study, she found targets in water were overestimated relative to targets of the same distance in air for distances greater than 50 feet.

Luria, Kinney and Weissman (1967) report results somewhat contrary to Ross. For distances between 4 feet and 15 feet the authors found an overestimation of apparent distance for stimuli in the water, relative to actual distance, while the air estimates were fairly accurate. The water measurements were substantially greater than the equivalent air measurements for greater distances as reported by Ross. Since the measurements were taken in a turbid lake, Luria, et al. attribute the overestimation of distances underwater to the almost complete scattering of light-rays by the water, resulting in excessive homogeneity of stimulation and absence of distinct cues. Contrary to size-distance invariance hypothesis, the authors report increased apparent size underwater concomitant with increased apparent distance. Kent (1966) also reported overestimation of actual distances for underwater stimuli placed further than 3 feet from the diver, but apparently little distance estimation error was found below 3 feet.

In an effort to clarify the effects of turbidity on size-distance estimations Kinney, Luria and Weitzman (1969) took distance estimations of targets ranging from 2 to 16 feet from the subject, in clear and turbid water conditions. They report a resolution of the conflict between overestimation found in field experiments, and the underestimation expected from optical principles. Underestimation was found to be effective only under ideal conditions of clear water and distances within "about arm's length or less." Under all conditions the authors report overestimation of the optical distance, with this overestimation actually exceeding the physical distance under poor viewing conditions. They found that low contrast, diffusely illuminated homogeneous field of view, uniform visual stimulation, and a paucity of distinct visible stimuli interfered with accurate depth perception, yielding an overestimation of distance. In an above water study designed to investigate the overestimation of apparent distance, Luria and Kinney (1968) found that lack of specific cues and loss of target contrast both contributed to overestimation of target distances, although the magnitude of overestimation was much greater for situations lacking in distance cues than for those with low contrast only.

There appears to be some lack of agreement in the results of the distance estimation studies, although overestimation of apparent distance relative to actual distance and air estimates appear to be consistently reported. This error in accuracy of distance estimation is most probably due to the reduced contrast and loss of normal distance cues in the water. Luria, et al. (1967) also attribute the overestimation of distances to homogeneity of stimulation and absence of

distinct distance cues caused by the almost complete scattering of light-rays by the water. Of interest here is the fact that none of the above studies provide results predicted by the optical changes occurring through a water-air interface. The loss of distance cues placed far from the diver introduces confusion into the interpretation of results.

None of the above studies were specifically concerned with the optical changes and attendant distance estimations within arm's length reach distances; although Luria, Kinney and Weitzman (1969) report underestimation under ideal conditions for targets within arm's length reach. These results indicate some difference between estimations made for targets at very close distances and those at greater distances. The present investigation attempts to concentrate on apparent distances within arm's length reach, as it is felt that these distances will be less affected by the problems of loss of contrast and illumination found in previous studies. Additionally, the information on distance estimation and its attendant response at arm's length distances should prove pertinent in preparing man for work in the undersea environment. It was also thought that more accurate distance estimations, reflecting optically altered apparent distances, could be obtained at closer distances, since additional cues are available that are less effective for judgments of greater distances.

#### Physical Principles Underlying Water-Air Distance Distortion

The amount and direction of optical distortion of apparent distance can be accurately determined by application of physical principles

to the passage of light rays through media of differing density. Since the angle of incidence ( $\theta$ ) of an incoming ray is subject to the laws of refraction ( $n_1 \sin \theta = n_2 \sin \phi$ ) and the refractive indices ( $n$ ) of air, water and glass are different, refraction of incident rays through water-glass and glass-air interfaces can be calculated. Figure 1a illustrates the passage of light rays from an air environment through glass to air again. With identical refractive indices before and after the glass, the light rays leaving the heavier medium will travel parallel to the direction they enter ( $\theta = \phi$ ). In a situation where visible light reaches a diver through a conventional facemask, the passage of light will be from water through glass to air (Figure 1b). Since the refractive index for water differs from that of air, the angles  $\theta'$  and  $\phi'$  will be unequal; thus light leaving the glass is no longer parallel to the direction from which it entered. Therefore, the visual angle (and the resulting retinal image subtended by the stimulus) will be greater in the water-glass-air viewing condition than in the air-glass-air viewing condition.

Typical values for the refractive index of glass are 1.50 to 1.60, with an average of approximately 1.54. The refractive index of air is 1.00, by definition, while that of water is 1.33. Because of the relative thinness of the standard glass faceplate (approximately 3 mm.) minimal distortion will be contributed by the glass, and its effects will be generally omitted from the following discussion. Emphasis will be placed on a theoretical water-air interface. Since the refractive index of water is 1.33 times that of air, an increase in angle of incidence of 1.33 is anticipated for light rays passing through this

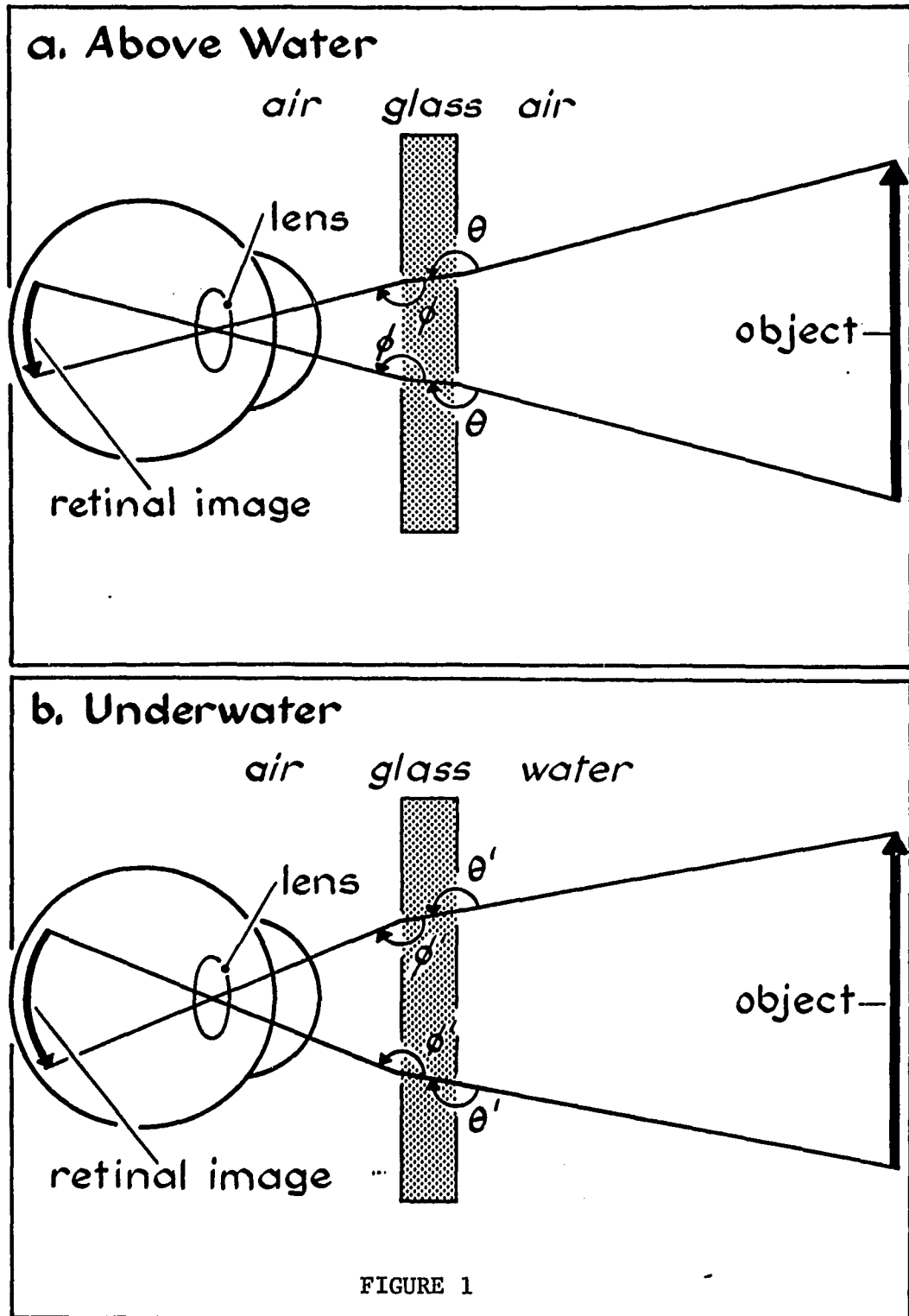


FIGURE 1

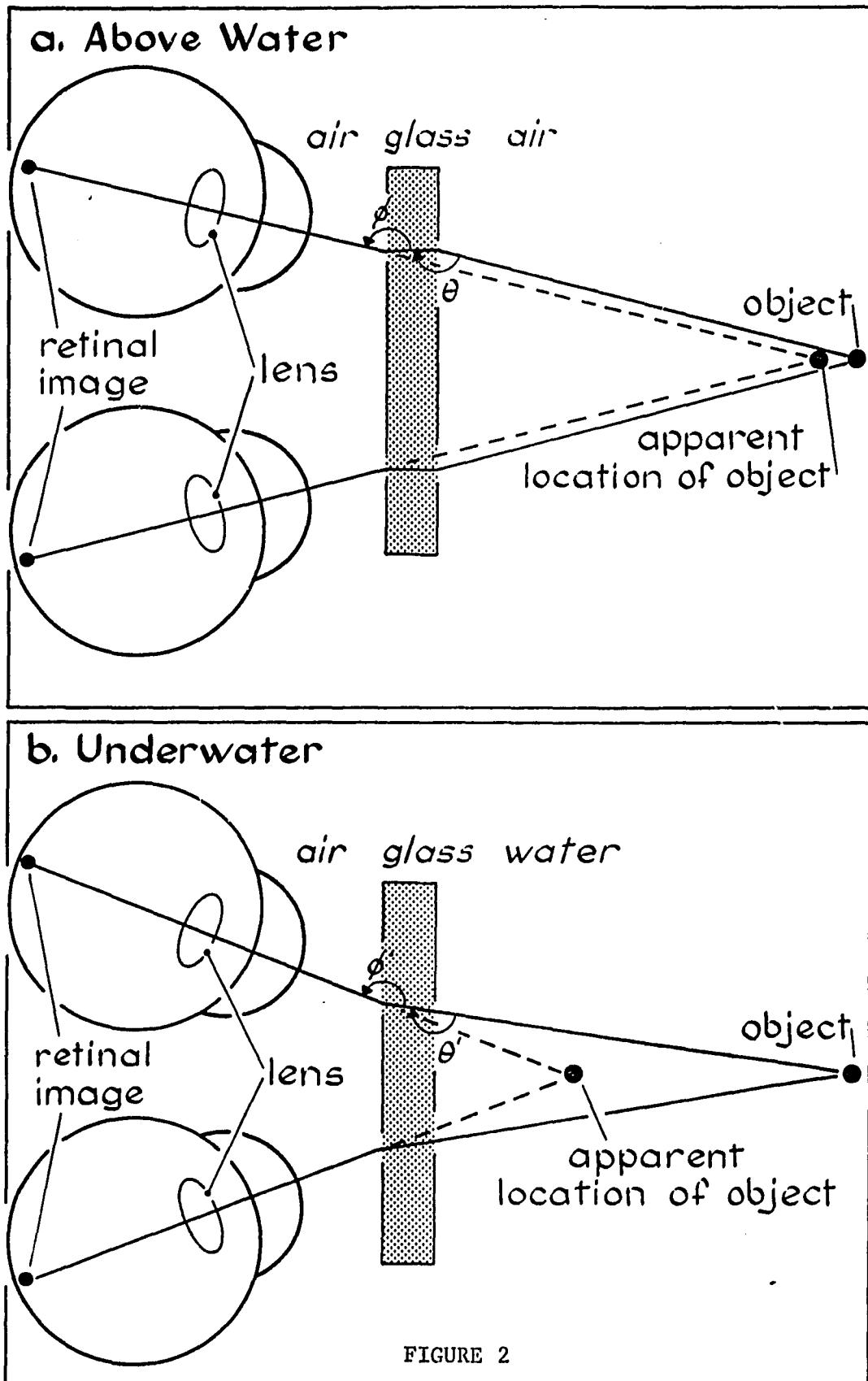
Visual Angles and Retinal Images

Under Two Viewing Conditions

interface, causing retinal size to also be increased by a factor of 1.33.

Because the retinal image in an underwater viewing situation is considered to be increased by this factor of 1.33, an object of a given size in air would have to be  $3/4$  closer to the eye to match the enlarged retinal image underwater. Since this is the case, the perceived distance of an object could be considered as a function of increased visual angle subtended by the object. However, Gogel (1963, 1968) demonstrated that retinal size cannot serve as a cue to absolute distance unless the actual size of the object is known. Recognizing this relationship, Ono and O'Reilly (1969) have shown that the change in retinal angle cannot be the explanation for decrease in apparent distance underwater, since subjects unaware of the actual size of the stimulus still underestimated the distance of the object when viewed in water.

Additional processes are necessary to explain change in apparent distance underwater. Two such processes thought to be involved in perception of decreasing apparent distance underwater are convergence and accommodation, as both are based on muscular feedback and are recognized distance cues for close (arm's reach) distances (Gregory, 1966; Ross, 1968a). Figures 2a and 2b illustrate the increased convergence of the eyes when attending an object at a fixed distance while viewing through a water-glass-air interface. Here the convergence is greater due to the greater divergence of the light rays upon leaving the glass. Figure 2a illustrates some change in apparent distance due to the effect of the glass, but this effect should be negligible for



Convergence of the Eyes

Under Two Viewing Conditions

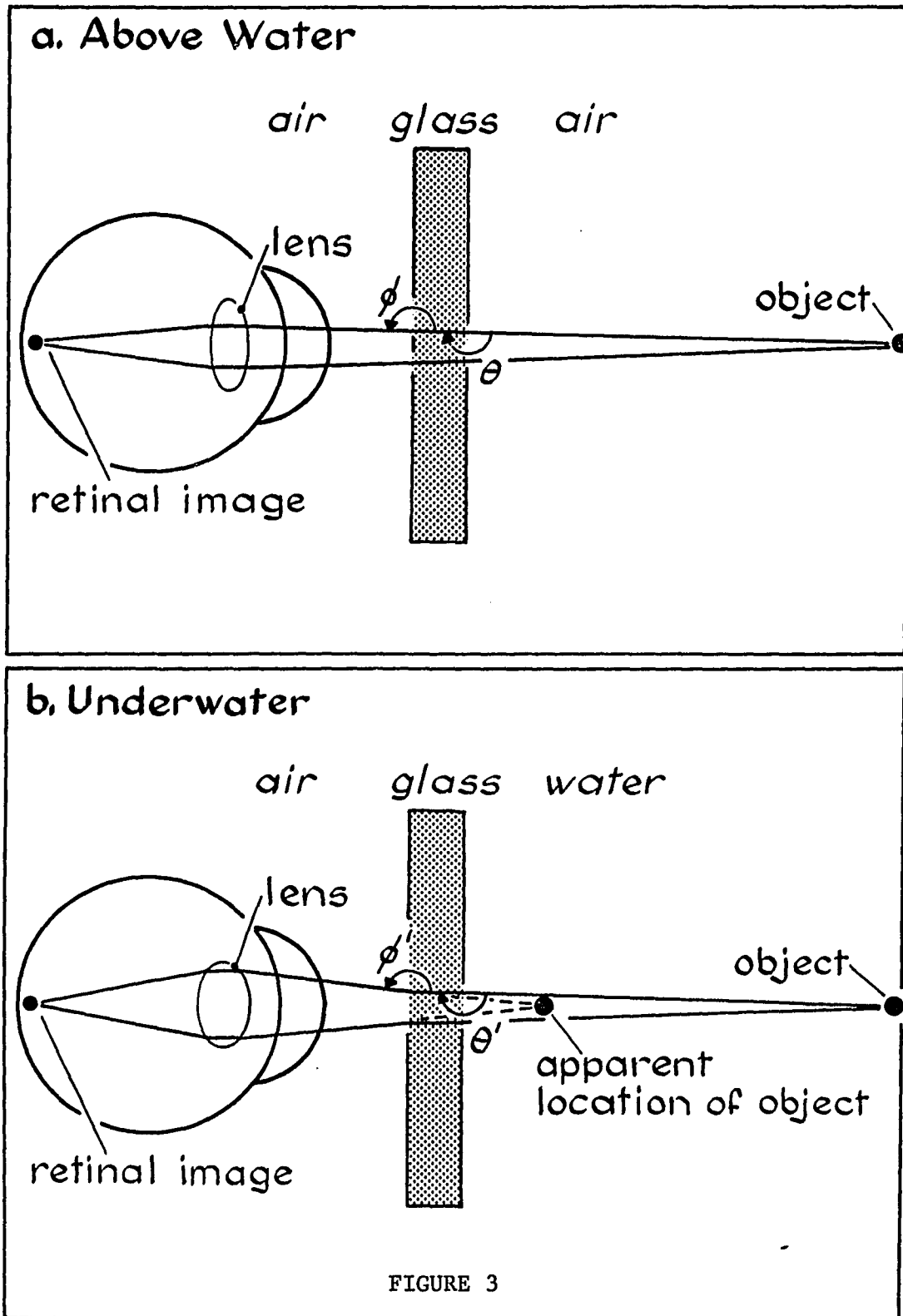
thin plates, and is depicted by a straight line through the glass in Figure 2b. Since convergence is a known cue to distance, change in the degree of convergence, reflected by change in the angle of incident light after passing through media of different refractive indices, should contribute to change in apparent distance of an object when viewed underwater.

Figures 3a and 3b depict the increased accommodation needed for viewing through the water-glass-air interface relative to the air-glass-air interface. In the former condition accommodation should increase because of the greater divergence of the light rays after they leave the glass. Since this change in accommodation is correlated with change in the refractive indices of the media through which an object is viewed, the process might also serve as a cue to distance and be a mediator of decreased apparent distance in water.

The loss of accommodation and convergence as cues to change in apparent distance underwater may contribute to the cross-over effect in distance estimation noted by Kinney, Luria and Weitzman (1969). Use of distances within arm's reach should provide the best opportunity for testing adaptation to this underestimation.

#### Adaptation to Distance Distortion of Targets Within Reaching Distance

Kinney, Luria, and Weitzman (1968a) investigated eye-hand coordination and adaptation over time for divers estimating distances within arm length. They report complete adaptation to distance distortion occurring immediately for experienced divers. Novice divers tended to underestimate apparent distances initially, reaching complete



Accommodation of the Lens

Under Two Viewing Conditions

adaptation within 15 minutes after working on various underwater tasks. Subjects with no experience in viewing underwater were found to show considerable reduction in error of underestimation over time, although they never reached the level of proficiency of the more experienced divers.

Unfortunately, there are numerous design errors in this study, including: too few subjects (only two experts, four novice divers, and two completely inexperienced subjects), and a rather arbitrary definition of experience. The task was conducted in four feet of water, with the subjects floating on the surface using a facemask and snorkel. The "inexperienced" divers were said to have had "fairly extensive snorkel-facemask exposure and some SCUBA experience;" it appears as though the "inexperienced" divers were skilled enough in the task they were asked to perform to be considered "experienced." The study does show, however, that adaptation to distance distortion underwater can occur for subjects with diving experience.

A study by Ono and O'Reilly (1969) demonstrated that both novice and experienced divers produce apparent distance measures closely matching those predicted by the laws of refraction, i.e., stimuli in water appear to be located at approximately  $3/4$  the real distance from the diver. The authors also reported some tendency for underestimation of real distance of objects when viewed in air, for stimulus distances from 6 inches to 18 inches from the faceplate mask. There was no difference between experienced divers and novice divers in estimation of target distances, except for the maximum stimulus distance (18 inches) with both the diver and stimulus underwater. In this situation the

expert diver gave distance estimation greater than the location of the virtual image and closer to the real location of the object, possibly indicating some conditional adaptation to the visually distorted stimuli due to prolonged experience with visual distortion underwater.

An additional investigation by Ono and O'Reilly (1969) dealt with varying psychomotor tasks performed underwater and measuring the amount of adaptation occurring over time. The authors found considerable adaptation to distance distortion over time when the diver performed specified visual-motor tasks, as contrasted with a tendency for distance estimations in the opposite direction by divers spending an equivalent amount of time underwater without working on eye-hand tasks. There was considerable task specificity in producing adaptation, with fine-motor tasks providing less adaptation than ballistic movement tasks designed to provide maximum feedback of errors caused by reaching for displaced stimuli.

The existence of adaptation over time, as reported by Ono and O'Reilly (1969) corroborates earlier observations of Barnard (1961), who found that increased magnification in water led to mistakes in size and distance judgments, which were "quickly overcome" with experience. Ross (1965a) also observed that initial errors in reaching by experienced divers rapidly adapted out with practice. Ross (1968a), based on evidence that experienced divers judge distances more accurately than inexperienced divers, postulates perceptual learning of the effects of underwater distortion, where divers may relearn the meaning of visual cues when viewing targets underwater.

While there is considerable disagreement between the results of Kinney, et al. (1968a), who reported immediate complete adaptation to distance distortion underwater for experienced divers, and Ono and O'Reilly (1969), who found a gradual increase in adaptation over time, a major difference in the two studies is the dependent measure utilized. The former group used a measure of adaptation within the distorted environment, or an underwater distance estimation task, as an indicator of adaptation. The latter study used the more conventional after-effect measures, reflecting over-estimations of target distances in air after exposure to the underwater distortion. The underwater measures have the face validity of demonstrating responses to stimuli in the distorting environment, but are faced with the problem of confounding by conscious correction which can inflate adaptive effects. If the divers are aware of the distortion effects observed underwater, and Kent's (1966) report indicates they are, then it is relatively simple and natural for them to consciously respond in the 'appropriate' manner. Use of the after-effect measure effectively reduces the inflationary effect of this variable (since conscious correction is opposite in direction to the after-effect) and provides a measure of the perceptual restructuring which is thought to occur on a physiological level within the diver.

In addition to not agreeing with the after-effect experimental results, Kinney, et al's (1968a) results fail to agree with these observations of Ross (1968a) and Barnard (1961), who noted initial error in eye-hand movements underwater, decreasing with time and practice. While aimed at a more encompassing problem, the present investigation attempts to resolve this conflict in empirical results

by providing measures of adaptation from both after-effect and underwater performance.

Irrespective of this controversy, there is little doubt that adaptation occurs to visual distortion caused by optical bending at the water-air interface. Adaptation also appears to be facilitated when tasks are designed to provide appropriate eye-hand manipulations and discrepancy feedback. This is in agreement with considerable evidence from laboratory experiments that measurable amounts of adaptation can be observed when visual input is placed in conflict with proprioception.

#### Adaptation to Visually Distorted Input

Optical distortion, often produced by viewing through prism spectacles, has been consistently found to cause many reaching and pointing errors when the prisms are first applied (Held and Hein, 1958; Kohler, 1962; Harris, 1965; and Hay and Pick, 1966). After practice there is considerable improvement, often with complete recovery to an errorless state. Removal of the lenses causes temporary overcompensatory movements on the part of the viewer, indicating that some adaptation has taken place in the individual's visual-proprioceptive system.

A degree of controversy still exists concerning the actual method of adaptation. Held and Hein (1958) found that for correction of errors of eye-hand coordination after displacement of the visual image by prisms it was necessary to have self-produced movement. Passive movement of the hand by the experimenter was not enough to provide the necessary feedback to the S to re-align the hand movements with the visually displaced targets.

To explain this phenomenon Held has reintroduced the concept of "reafference," which was defined by von Holst (1954) as feedback stimulation produced by self-initiated movements of the sense organs. The concept is differentiated from "exafference," or stimulation occurring to a passive sense organ by some external force.

In a later experiment Held and Schlank (1959) found that reafferent visual stimulation was necessary for learning new eye-hand coordinations when subjects were tested on a device utilizing mirrors to displace the visual image. Again passive movement of the arm failed to allow for adjustment to the distance-displaced visual image. Only by observing his arm while actively moving it was the subject able to correctly adapt to the displaced image.

Numerous investigations have been provided by Held and associates to substantiate the necessity for reafferent movement. Held and Hein (1963) found reafference necessary for full and exact adaptation to sensory rearrangement in kittens. Using pairs of neonatal kittens divided into active, or movement producers, and passive, or movement receivers, they demonstrated that visually guided paw placements, discrimination on a visual cliff, and blink responses were normal for the active kitten, but failing for the kitten deprived of active movement.

Held and Rekosh (1963) attempted to refine the reafference theory by stating the important item in adaptation was that it takes place due to the interaction between conflicting visual and proprioceptive sensory inputs. While Held has "repeatedly emphasized the production of movement (efferent activity) as the prime casual factor (in prism-inducing after-effects)" (Held, 1963), he has more recently added that

the establishment of a meaningful correlation between the individual's self-induced movements and the visual input is necessary to provide a new response to the displaced visual input through some feedback loop (Held, 1965).

Hamilton and Bossom (1964) also utilized prismatic displacement to test Held's theory of reafference. They reported that there was no difference in magnitude of decrease of after-effect between a group with reafference and a nonreafferent group. Since reafference did not improve the elimination of after-effects more than nonreafferent conditions, the authors questioned the assertion that the processes underlying adaptation to prismatic distortion and normal perceptual development are identical. This study, plus Hamilton's (1964) study of intermanual transfer, challenge the reafferent interpretation of adaptation results. These criticisms are, however, built on the assumption that the variables which regulate adaptation should also regulate the dissipation of after-effects. There is at present no unequivocal evidence that the process underlying acquisition also influences forgetting in the same way.

Kravitz and Wallach (1966) found significant adaptation to prismatic displaced visual stimuli when subjects observed their immobile forearm while it rested on a vibrating board. They contend that self-produced movements are not necessary for prismatic displacement adaptation. Self-produced movements and vibrating stimulation are both thought to operate by enhancing the central effect of proprioceptive stimulation representing the true arm position.

Two additional series of investigations have appeared to challenge Held's concept of reafference. Canon (1966) manipulated visual input with the customary prisms and auditory input with electronic "pseudophones." Ss were informed to attend to one or the other of the conflicting modal stimuli. When told to localize in terms of vision, there was significant adaptation in the auditory sense, with attention drawn to audition there was adaptation in the visual sense, and a small amount of auditory adaptation. The study demonstrates that adaptation may develop in the absence of any feedback from self-initiated movements. Canon states that adaptation can occur when there is discrepancy between the location of a stimulus through one modality (which provides a basis for efference responding to the stimulus) and its location as determined by another modality.

The effect of efference has been carefully investigated by Burnham (1966) and Festinger, Burnham, Ono and Bamber (1967). Festinger's theory differs from Held's in that perception is thought to be the learned readiness to respond initiated by retinal stimulation, not simply a function of active movement. Adaptation to prismatically induced curvature was found for subjects under a "learning condition," but not for subjects under an "accuracy condition," where both conditions had essentially the same reafferent proprioceptive feedback. The studies found that Held's distinction between active and passive movement is too gross. Distinctions concerning the nature of the efference must be made. Not all active or self-produced movement results in adaptation, the important variable is whether or not the active movements are learned, causing efferent readiness to be activated.

The general conclusion from the above studies is that reafference, in Held's sense, is one important determinant of adaptation, but is not exclusively necessary under all conditions. In addition, there is some evidence that reafference itself may be too encompassing a term, and that efferent readiness may someday replace it.

### Visual or Proprioceptive Adaptation - An Area of Conflict

Harris (1965) has specified six possible interpretations that might account for adaptation to optical distortion:

1. Conscious correction - deliberate correction of performance,
2. Visual change - change in perceived location of objects,
3. Shift in perceptual axes - shift in the reference axes for all spatial perception,
4. Visuo-motor recorrelation - change in the correlation between visual inputs and motor responses,
5. Motor learning - learning new muscular responses,
6. Proprioceptive shift - hand feels to be where it visually appears to be.

Although these six alternatives were originally presented in the context of eye-hand coordination experiments, Harris has extended their application, with varying degrees of credibility, to other adaptation experiments. From results on tests designed to measure transfer of adaptive hand-coordination from a visual task to auditory and body orientation problems Harris had concluded that a proprioceptive shift in felt hand position (or arm) relative to the body is basic to displacement studies.

In a comprehensive series of experiments Hay and Pick (1966) investigated the question of which system, vision or proprioception, adapts to conflicting information produced by the displacing prisms. They investigated whether the optically displaced visual system always

draws other systems into alignment with itself, or whether adaptation can occur within the visual system. Six coordination tests were devised and administered over 144 hours of prism exposure. The tests designed to confirm the occurrence of non-proprioceptive adaptation were:

eye-hand coordination changes  
 ear-hand coordination changes  
 ear-eye coordination changes  
 eye-hand coordination changes  
 ear-head coordination changes  
 head-hand coordination changes

Their conclusion was that adaptation occurs in both visual and proprioceptive systems to optical displacement, with the proprioceptive adaptation occurring first (the short exposure times used by Held thus biased his results toward proprioceptive adaptation). Visual adaptation was found to occur as a long term effect after a large number of nonvisual stimuli were placed in conflict with vision, including body exposure. The authors tentatively ascribe this visual adaptation to some "sensed" eye position which modified eye posture.

McLaughlin and Bower (1965) also found a change in the apparent position of the visual target, which they attributed to "change in felt position of the eye." Using a study on intermanual transfer the authors found adaptive shifts to subjective 'straight ahead' for the adapted hand, but no change for the nonadapted hand. In a visual target marking test intermanual transfer was almost complete. Thus the authors conclude there are two components in adaptation to displacement: proprioceptive shift and change in felt position of the eye, a conclusion also supported by McLaughlin and Rifkin (1965). Hamilton (1964) and Epstein (1967) criticize these hypothesized changes

in felt position of eyes, although photographic measurements secured by Kalil and Freedman (1966) showed persistent lateral rotation of the eyes after prism exposure - subjects were not aware of these rotations.

Further investigations have been performed in an effort to solve the controversy over change in proprioceptive systems versus change in visual systems, with the results still not amenable to clear interpretation. Rock and Harris (1967) report results in agreement with Held's original conclusions: that visual information determines what is perceived when visual and tactile information are placed in conflict. Objects felt while viewed through a minification lens were judged to be smaller than actual, illustrating agreement with vision not with actual felt size. They also found that after "prolonged" exposure, up to thirty minutes, touch information was still misperceived even with the eyes closed.

Rock and Harris feel that vision is dominant over touch to such a degree that tactual and kinesthetic information in conflict with vision is either ignored or altered to be consistent with visual input. Hay, Pick and Ikeda (1965) introduced the term "visual capture" to stress this complete dominance of vision over touch.

Kinney and Luria (1969) confirm the phenomenon of "visual capture" using magnification in size of objects viewed underwater. Selection of familiar coin-size discs by inexperienced divers was found to be based on optical size, not actual size, of the stimulus, although subjects were allowed tactual feedback regarding felt size. Even when allowed to view the coin-discs in relation to their own hand, discs were chosen considerably smaller than actual size, but in close agreement with optical size.

Harris (in Rock and Harris, 1967) offered change in the position sense of the arm as an explanation of adaptation to sideways displacement of prism-distorted visual stimuli. By utilizing a pointing response to stimuli, the author sought to determine if change in pointing after adaptation arose because of change in target locations (visual shift) or change in position of arm (proprioceptive shift) - results indicated it was the latter. Harris argues from this that all adaptive changes are caused by altering felt position of the limb. The co-author Rock believes that visual proprioception can be altered if enough other modal input information is present to conflict with vision. Conflicting touch information alone is not enough to alter visual perception. Numerous additional studies have shown change in proprioceptive positioning of various body parts after exposure to prism displacement (Hamilton, 1964; Harris, 1963, 1965; Shaffer and Wallach, 1966; Wallach and Frey, 1969).

All of these results are contrary to the classical theory of perception held by Berkley, Dewey, Helmholtz, etc., which argues that visual structure is developed through tactual experiencing. Russian psychologists, in particular, still hold that touch teaches vision, with tactual perception being more primitive ontogenetically than visual perception (Pick, 1964). While contemporary evidence clearly supports the concept of visual dominance, change in visual perception may be demonstrated with the appropriate experimental procedures.

Festinger, Burnham, Ono and Bamber (1967) hypothesized that change in visual perception would be more difficult with ordinary prism spectacles than with prism contact lenses. Their thought was that eye

movement with prism spectacles must be in conformity to the retinal image and not the objective contour; but that eye movements would conform to the objective contour rather than the retinal contour with prism contacts. One study using prism contact lenses found complete visual adaptation to curvature after only a short period of scanning; confirming the theory that efferent readiness relevant to eye movement is important for change in visual perception. Festinger, et al. (1967) also provide one of the few unequivocal studies demonstrating change in visual perception to prismatically induced curvature while using proprioceptive feedback from arm movement.

#### Inducing Visual Adaptation

In reporting the occurrence of visual adaptation investigators have had to resort to either long term exposure to distortions or experimental manipulation of the stimuli conflicting with the distorted visual input. Movements of body parts by the observer have been generally recognized as producing important cues for adaptation. Rock (1968) notes that direct view of one's body is also a powerful source of veridical cues. He asserts that when viewing through prisms, extreme familiarity with one's body readily causes recognition of distorted visual cues, with subsequent acceleration of adaptation to distortion.

Rierdan and Wapner (1966) criticize Held, Harris and others who focus on changes in sensorimotor behavior and proprioceptive awareness independent of other perceptual cues (both body and object), and conceptual activity. They found that adaptation to rotation of the

visual field involved the establishment of a stable correspondence between body perception and object perception. They also noted that the form of adaptation varies dependent upon conceptual attitudes introduced and the nature of visual stimuli and sensorimotor activity permitted.

Exposure to one's body has also been reported to induce visual adaptation by Hay and Pick (1966). They found that a body-exposure condition, during which the subject saw his own movements and their consequences, placed a great many stimuli in conflict with vision. In this condition, visual adaptation increased, with a consequent reduction in proprioceptive adaptation "when the 'feel' of the whole body is put into conflict with vision." (Wallach, Kravitz and Lindauer (1963) report rapid adaptation to prism distortion for subjects in a passive condition looking at their legs; however, their results, although inconsistent, appear to reflect change in the proprioceptive sense.)

Apparently, body exposure involves a high degree of discrepancy between vision and other sensory systems. Hay and Pick, like Rock (in Rock and Harris, 1967), determined that inducing visual adaptation requires putting a great variety of nonvisual stimuli into conflict with the optical displacement. One of the most effective methods of inducing visual adaptation is allowing the observer to view his body in the distorted visual field.

Studies based on Festinger's theory of perception, which proposes that the conscious experience of perception is determined by a set of efferent readiness activated by afferent visual input, have also

produced evidence for visual adaptation (Festinger, et al., 1967). Festinger and his associates have demonstrated that very similar tasks can produce different amounts of adaptation if the tasks vary in amount of learning of new afferent-efferent associations. To enhance the opportunity for visual adaptation, as viewed in these terms, tasks creating greater changes in efferent readiness are considered to produce greater visual adaptation.

In summary, while the majority of available reports appear to support a proprioceptive interpretation of adaptation to optically distorted stimuli, the typical exposure times are not comparable to the long-term exposures of 144 hours and 42 days reported by Hay and Pick, nor do they necessarily provide exposure situations equivalent to those encountered by a diver with prolonged experience functioning in a visually distorted environment. It has not been resolved what form of adaptation would be expected after prolonged exposure to visual displacement produced by water-air distortion.

#### Conditional Adaptation

Some investigators (Ono and O'Reilly, 1969; Kinney, Luria and Weitzman, 1968a; Ross, 1965a, 1968; Barnard, 1961) report that experienced divers adapt readily to underwater distortion, reflecting the possibility that conditional adaptation occurs for the experienced diver. If the numerous cues uniquely available to the diver, such as feel and sound of regulator air exchange, weightlessness, and additional cutaneous sensations attendant with performing underwater are important in providing a situational set for determining perceived distance, then there would be a stronger possibility of finding adaptation on a

selective basis. That is, the subject may utilize one set of cues for perceiving distance in one situation, and a different set of cues, or a different method of integrating the available cues, in a second situation. If the various distance cues are linked with sufficiently different situational factors, then competing systems for perceiving distance may exist simultaneously in the individual.

Such conditional adaptation to distorted visual input has been demonstrated by several investigators. Kohler (1951, trans. 1964) found that subjects adapted to viewing through spectacles which contained plain glass in the bottom half and a prism in the top half. Depending on the position of the eye the visual stimuli would be different, but, after a period of adaptation, the subjects were able to shift from lower (normal) to upper (prism distorted) input with no difficulty.

Recent studies finding situational adaptation have tended toward a "gaze contingent" interpretation of this phenomenon (Pick and Hay, 1966). These experiments, and one by Kohler (1962) utilizing spectacles with split color fields (a later replication by Harrington (1965) was generally unsuccessful), have reported situational or conditional adaptation; where interpretation of different inputs provide the same perceived image although the incoming physical stimuli are vastly different. Whether this result is dependent on the position of the eye (gaze contingent) as advanced by Hay and Pick, or contingent on changes in phenomenal direction of eye (ego-centric localization) as suggested by McLaughlin and Bower (1965) and Epstein (1967), the existence of differential input stimuli producing a consistent,

veridical perceived image provides some indication for accepting the possibility of conditional adaptation.

#### An Approach to Understanding Adaptation to Underwater Distortion

Use of highly experienced divers has been considered in the present study to provide a situation analagous to the prolonged prism exposures reported by Hay and Pick (1966), if this considerable experience to underwater distortion can be recovered with minimal adaptation "warm-up." Based on previous reports, experienced divers appear to exhibit an ability akin to conditional adaptation when performing in a water distorted environment. Considering the dangerous nature of the situation in which the diver is placed, it is not surprising to expect implementation of a restructured coordinating system capable of providing the most efficient responses in an emergency.

It is this author's contention that visual recoding of displaced stimuli would be the most effective adaptive response where coordination of several body members might be required. Change in felt-position of a body member can be expected to occur with initial exposure to a distorted environment, since the visual system has been shown to dominant over the proprioceptive system, drawing discrepant positioning input into line with the visually distorted sensations. Over time, proprioceptive adaptation is ineffective, since restructuring of each body part would have to be accomplished individually, while discrepant localization still occurred between visual, auditory and other senses. It is hypothesized that only by drawing the visual system into agreement with other senses, through recoding of incoming visual input, could an effective system of adaptation be provided for conditions of

long-term exposure such as that experienced by Stratton (1897), Helmholtz (1925), Kohler (1962), Hay and Pick (1966), and expert divers.

The present investigation will attempt to reconcile some of the contradictions arising between studies purporting to demonstrate proprioceptive adaptation and those finding visual adaptation, by utilizing the established ability of divers to adapt effectively to distance displacement produced by refraction of visible light through a water-air interface. Use of experienced divers, with long exposure to a naturally 'distorted' environment, provides a unique comparison to the typical short-term studies dominating adaptation literature, and the few extensive prism exposure studies available. If the experienced divers have established some sort of visual-motor reconnection contingent on the environment in which they function, then a brief exposure to the underwater distorted distances should be sufficient to provide a situation analagous to long-term prism exposure.

Since Festinger et al. (1967) demonstrated that very similar tasks providing different learning of afferent-efferent associations produce different amounts of adaptation, the visual-motor tasks included in the present study must be carefully selected. Since emphasis is on determination of which sensory system (vision or proprioception) is most affected by exposure to underwater distance distortion, tasks were designed to provide maximum opportunity for visual and proprioceptive input to be placed in conflict with each other and additional perceptual cues and conceptual activity.

Pilot studies (Ono and O'Reilly, 1969) have demonstrated that viewing through a water-air interface is not sufficient to produce adaptation, feedback from tasks performed in the distorted environment are necessary before the diver reaches a measure of effective adaptive functioning. Selection of the most effective tasks from these pilot studies insured some measure of adaptation; development of appropriate dependent measures to differentiate which sensory system undergoes restructuring also had to be considered.

Several earlier investigators have demonstrated that exposure conditions effective in producing proprioceptive adaptation do not cause these adaptive shifts in reaching to transfer to the contralateral, non-working hand (Cohen, 1963; Efsthion, et al., 1967; Hamilton, 1964; Harris, 1963, 1965; Mikaelian, 1963; Mikaelian and Held, 1964; Rock and Harris, 1967). On the contrary, discrepancy between working and non-working hands has been used as a measure of proprioceptive adaptation in the working hand; while adaptive responding in the non-working hand has been taken as an indication of visual responding (Hay and Pick, 1966; Harris, 1965; McLaughlin and Bower, 1965; McLaughlin and Rifkin, 1965; Rock and Harris, 1967). Since it is a relatively simple matter to restrict performance to one hand, the present study adopted this definition of proprioceptive versus visual adaptation: If the working and non-working hands both adapt to the distance distortion experienced through a water-air interface, then visual adaptation occurs; if only the working hand adapts then this is evidence for proprioceptive functioning.

After-effect measures of distance estimations taken outside the water environment served as the major dependent variable in registering amount of adaptation. Use of after-effect response as a dependent measure is consistent with most adaptation studies. In an effort to more clearly delineate the effect of performance while in the water environment, distance estimation responses will also be collected at regular intervals underwater (as per Kinney, Luria and Weitzman, 1968a).

Numerous problems are evident when trying to determine the existence of visual and/or proprioceptive adaptation. First is the generality of the reported data to other forms of visual distortion and other conditions of exposure. As noted by Epstein (1957), few studies have utilized adaptation situations other than lateral displacement from prism distortion, tilt, curvature, and increased optical distance (minification). The difficulty of comparing long and short term exposure periods has already been mentioned; the majority of prism adaptation studies utilize approximately one half hour of exposure to distorted visual inputs, selectively biasing toward adaptation within the proprioceptive system.

Additional difficulties exist in defining adaptive responding to water-air distortion, since visual adaptation to prism distortion is thought to occur with "felt position of the eye" (Hay and Pick, 1966; McLaughlin and Bower, 1965), or with efferent readiness relevant to eye movement (Festinger, et al., 1967). It is possible that the muscular accommodation and convergence cues available for the type

of distortion to be investigated may not operate in an entirely analagous fashion.

Since the correlation of information on effector commands sent to the musculature of the body and the visual feedback of the resulting efferent responses are thought by many to be the basis for adaptation, consideration must be given to the development of appropriate correlated movements. It has been suggested that after practice with active movements in a distorted environment, subsequent adaptive movement is initiated based on newly stored correlations different from those stored for effective movement in a different visual field.

Loss of one-to-one correlation between effector commands and visual feedback, labeled decorrelated feedback, can provide gross visual-motor disarrangements characterized by increased variability of motor responses (Held and Freedman, 1963). In a weightless state, such as can be expected in water where the diver is neutrally buoyant, perceptual-motor defects and inability to establish new afferent-efferent connections is possible, although the available literature reveals the existence of almost complete adaptation for experienced divers. In studying visual stability during bodily movements underwater, Ross and Lennie (1968) found good visual stability during active movements but poor compensation for slow passive movements.

Nevertheless, the diver must contend with numerous factors which could retard the development of adaptive responses, particularly weightlessness, greater viscosity of water, and restriction of movement due to protective clothing and supportive gear. In the present study most of these factors will be recognized as uncontrolled variability

within the design, with the expectation that they will actually serve to enhance the conditional adaptation within the diver due to their environmental specificity. A variable that could potentially provide decorrelated feedback would be the reduced effect of gravity; this effect can be fairly tightly controlled by making the subject heavily negatively buoyant relative to the items that must be manipulated. Losses in performance due to the effects of cold on the hands has been found in air (Fox, 1967) and water (Bowen, 1968), most probably due to peripheral shutdown of the vascular system with resulting loss in skin temperature. With heated pool water and short exposure times, loss in underwater performance effectiveness can be kept to a minimum.

Further difficulty with considering the underwater environment as equivalent to the normal air environment occurs when the amount and types of visual stimulation are considered. In the water the diver is subject to a reduced visual field due both to the shape of the standard facemask and rapid loss of detail and contrast with scattering of light. Stereoacuity loss and perceptual narrowing due to stress also have been reported for subjects functioning in water. As discussed above, these factors are potentially destructive to adequate visual performance in a water surround, but do not appear to warrant major consideration in the proposed study.

Recognizing these negative aspects to underwater work, it is still felt that the unique visual effects, combined with a ready pool of highly exposed and adapted subjects, made the testing of adaptation to distance distortion through a water-air interface both feasible and profitable. Use of underwater distortion as a factor in the establishment

of new afferent-efferent connections provided a test of the generality of existing adaptation theories and a new vehicle for the investigation of physiological and psychological restructuring to a perceptual phenomenon.

#### Summary and Hypotheses

Considerable disagreement exists among perception theorists as to the underlying bases for adaptation to visual distortion. While the preponderance of studies suggest a shift in proprioceptive restructuring due to "visual capture" of the less dominant sense, there is enough contradictory evidence available to question the generality of that conclusion. Visual adaptation has been established in numerous studies; particularly those requiring long term exposure to distortion and those utilizing tasks providing additional sensory input highly contradictory to the distorted visual input. Adaptation occurring for subjects exposed to distance distortion due to refraction of light rays passing through a water-air interface was investigated in an attempt at clarifying this controversy.

The following hypotheses were entertained concerning the amount and type of adaptation experienced by subjects exposed to underwater (U/W) distance distortion:

- A. Hypotheses concerned with responses where a measure of after-effect is the dependent variable:
  1. Experienced subjects will exhibit visual adaptation to the U/W distortion as measured by similar after-effects produced by both working and non-working hands.

2. Inexperienced (novice) subjects will exhibit proprioceptive adaptation to the U/W distortion, as exhibited by a difference in after-effects for working and non-working hands.
3. The experienced subjects will adapt to the water-produced distortion to a greater degree than the inexperienced subjects, at least in the initial stages.
4. Improvement in adaptation over time will occur for both experience groups.
5. With the introduction of the experimental tasks, adaptation will increase more for the Hi feedback subjects than for the Lo feedback subjects.
6. During the experimental session, visual adaptation will appear for the Hi feedback novice subject, as measured by a positive change in non-working hand responds.
7. Adaptation will continue at the existing rate for subjects receiving control (Lo feedback) tasks; no change from proprioceptive restructuring is anticipated for the Lo feedback novices.
8. Tasks designed to provide the most opportunity for ballistic movement will produce the largest increase in after-effect measures during the "adaptation" period.
9. Experimental tasks designed to provide high conflict between visual input and veridical referents will provide the largest increases in after-effect measures during the "experimental" period.

10. The magnitude of after-effect will proportionally increase with target distance from the subject.

B. Hypotheses concerned with distance estimations on an U/W task as the dependent measure:

11. Experienced subjects will exhibit greater initial adaptation to U/W distance distortion than will novice subjects.

12. Adaptation over time will be found for experienced and novice subjects.

13. Complete adaptation will be reached more rapidly by the experienced subject than by the novice subjects.

14. Errors in underestimation of distance will increase with target distance from the subject.

## CHAPTER II

### METHOD

#### Selection of Subjects

Sixteen experienced divers were selected from the local sport-diving community and randomly assigned to one of two experimental groups. A criterion of over 100 hours of ocean diving was originally planned as a definition for qualified experienced diver, but this was modified somewhat when the pool of available divers diminished. The median experience for the 16 "experts" was over 200 hours, with a range of 40 to 1200 hours; 5 had fewer than 100 hours, although they had an intensive number in the last year (40 percent to 100 percent of their total). Six additional divers had over 300 hours, with several divers reporting over 1000 hours of diving. All SCUBA divers reported considerable experience with skin diving (snorkel diving).

Sixteen novice divers were selected from numerous volunteers from the University and local diving courses. The only stipulation for selection of novice divers was familiarity with skin diving and/or SCUBA diving, with fewer than five hours of SCUBA experience. Restricting selection of novices to those with some experience handling skin-diving gear was thought to avoid Kinney, et al.'s (1968a) comment that complete novices fail to adapt to underwater distortion due to increased anxiety and focusing attention on breathing and not motor-performance. All novices reported considerable experience with skin-diving gear. It is felt that the movements involved in skin-diving are by their very nature, too restrictive to allow the establishment of new

eye-hand coordinations, but should present a breathing situation not too dissimilar to that found with SCUBA gear. Post-test interviewing found that overall anxiety was low for all novices, including those totally lacking prior SCUBA experience. One half of the novices had no previous SCUBA diving experience, but reported a median of 140 hours of skin diving. The other eight novices reported a median of 4.5 hours of ocean SCUBA diving, with only two exceeding the upper limit of 5 hours of SCUBA experience - both reported 10 hours of ocean diving.

All prospective subjects were administered a personal history questionnaire which asked their swimming ability (for safety reasons), their visual rating, whether they could see up to four feet without corrective lenses, and whether they wore corrective lenses ordinarily. Four subjects, three experienced divers and one novice diver ordinarily wore corrective lenses. The novice and two experienced divers wore contacts, and were allowed to wear them during the session. The third experienced S ordinarily wore a facemask with a built-in optical system; he professed to needing corrective lenses only for extreme distances and was allowed to participate with the mask supplied by the E.

The age of the divers varied over a range from 15 years to 52 years, with the experienced divers having an average age of 29, while the novice divers had an average age of 26 (this difference was found to be insignificant on a two-tailed t-test). Each group had one S in his teens.

Within each experience group the divers were randomly assigned to experimental and control conditions. Ss were tested in pairs, one experimental and one control in the identical task sequence. Random

selection of preferred and non-preferred hand was also accomplished within each group. One half of the subjects in each group were instructed to use their preferred hand during all underwater tasks, the other half used their non-preferred hand. The three Ss who were predominantly left handed were also randomly assigned to preferred (2) and non-preferred (1).

To provide a rough control for differential lighting, testing was scheduled at approximately the same time of day, and with similar weather conditions. Since testing was accomplished in an outdoor facility, some fluctuation in lighting and weather conditions occurred-- these were felt to be evenly distributed across the experienced and novice divers. Complaints of cold discomfort were noted in six sets of divers roughly matched between novice and experienced. Water temperature remained between 72° F and 74° F at all times, while ambient air temperatures and wind-chill factors fluctuated through a range normal for April and May, (estimated at 74° F - 82° F), the months the testing took place.

#### After-effect Testing Apparatus

Three measures of adaptation to underwater distortion were taken. Two measures, working and non-working hand, were taken from the device portrayed in Figure 4, the after-effect testing device of A-ETD. Basically, it is a large painted plywood tank, 48 inches by 30 inches by 16 inches, fitted with a facemask (Healthways, No. 1227) in the lower center of one end. The mask was rigidly attached in a direct line with the stimulus target, a two inch diameter black plastic disk suspended from a movable carriage by a brass rod. Positioning of the stimulus was

LEGEND:

- 1. Stimulus Target
- 2. Mounted Facemask
- 3. Ruled Response Slate
- 4. Guillotine Door Control
- 5. Stimulus Carriage
- 6. Pulley Control For Carriage
- 7. Position Marker For Stimulus

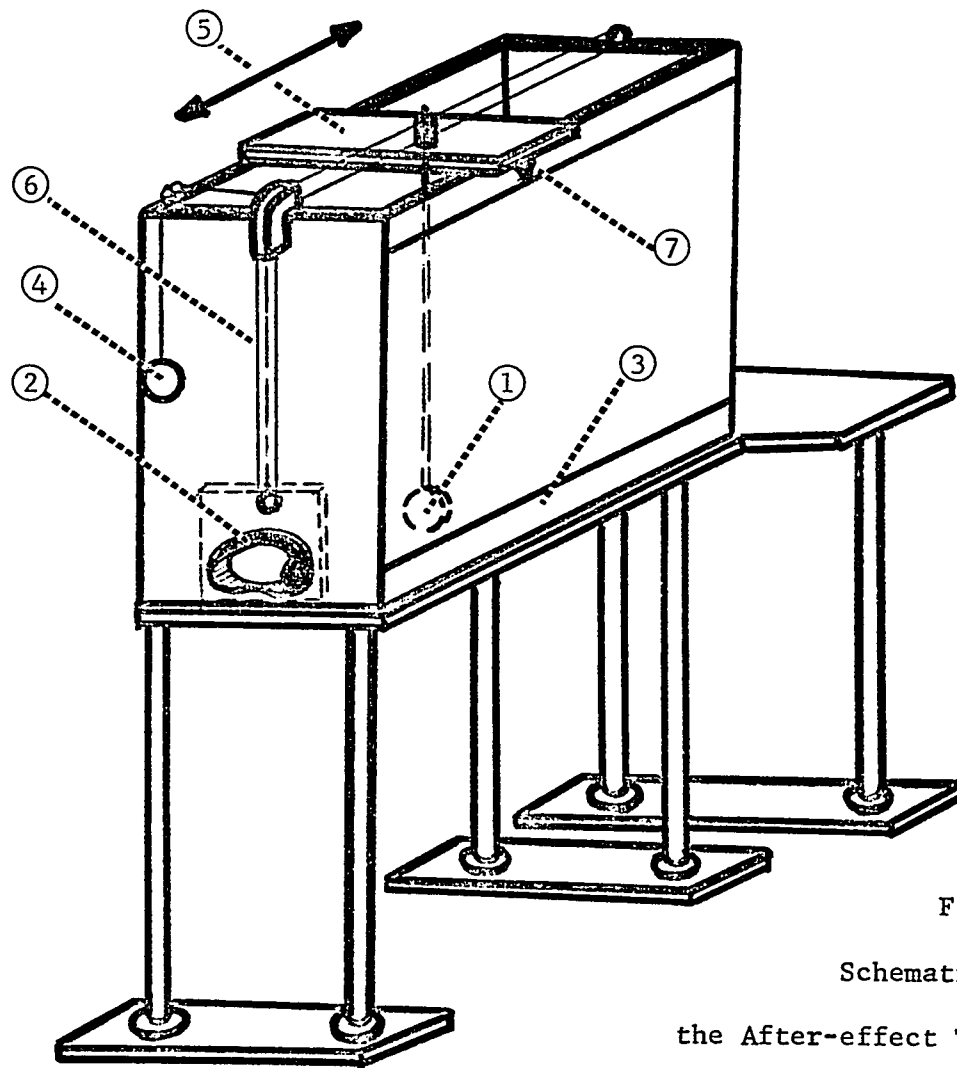


FIGURE 4

Schematic Drawing of  
the After-effect Testing Device (A-ETD)

accomplished by a single E through use of a pulley arrangement running the length of the testing tank. The stimulus carriage passed along tracks at the top of the tank, and distances were marked by a graded rule along the upper edge of the tank, on both left and right sides. Accuracy of left-right placement of the stimulus was found to be within 1/20th of an inch for 92 percent of the settings.

A six inch tunnel partially surrounded the front of the facemask, on the inside of the A-ETD, to block any view of the top of the tank and the stimulus carriage. The duration of stimulus exposure and onset of viewing into the interior of the A-ETD were controlled by raising and lowering a translucent screen in front of the facemask. The E was able to control both the screen and the movement of the stimulus carriage from either side of the tank.

The testing device itself rested on a supporting table, which contained tracks for positioning the SLIDE apparatus in its air condition. The support table also provided a storage area for data sheets, pens, pointers, sequence instructions, etc. An adjustable stool was provided for the subjects, and was arranged to allow a comfortable sitting position; all Ss were evaluated as to their ability to comfortably reach to and beyond the maximum stimulus distance.

The apparatus was constructed with a width narrow enough to allow the S to indicate apparent distances with either hand when he viewed through the facemask into the interior of the tank. The subject was asked to indicate with the appropriate hand where the target appeared to be located, to do this he was given a stylus and instructed to mark the perceived location along a measured slate running along the outside

of the A-ETD. Instruction required the S to return his hand to the front of the testing tank after each measurement, and to move with a smooth, rapid motion, not sliding along the side of the apparatus. The S could not see his hand or the ruled slate, but both were visible to the E, who entered the perceived distance on a waterproof data sheet. Measurements were made to the nearest 20th of an inch. All measurements with this device were taken with the diver sitting in water up to his shoulders, with only his head and hand above water. Thus a measure of after-effect was provided, minimizing the possibility of inflated or erroneous results due to conscious correction.

Test distances were 7 and 14 inches from the front of the face-mask glass. The distances were presented in randomized block design, with right and left hand measurements also randomized on each testing.

#### SLIDE Apparatus

An additional measure of adaptation was devised to examine the results of distance estimations reported by Kinney, Luria and Weitzman (1968a). This device (pictured in Figure 5) has been labeled the SLIDE apparatus since it consisted of a rectangular plywood board covered with parallel lines one inch apart and containing two movable red plexiglass markers on slide tracks. One marker was supported on a brass track on the top-side of the board and was controlled by the E. The second marker was positioned in a groove passing through the board, such that it could be controlled by the S from the bottom of the device. This latter sliding marker was placed under a covering which allowed a view of positioning accuracy to the E but not to the S. Measurements were taken to the nearest tenth of an inch. The

## LEGEND:

1. E Positioned Target Stimulus
2. S Positioned Marker
3. Ruled Lines on SLIDE Surface
4. Positioning Guides for A/W & U/W Mounting
5. Hinged Cover for S Marker

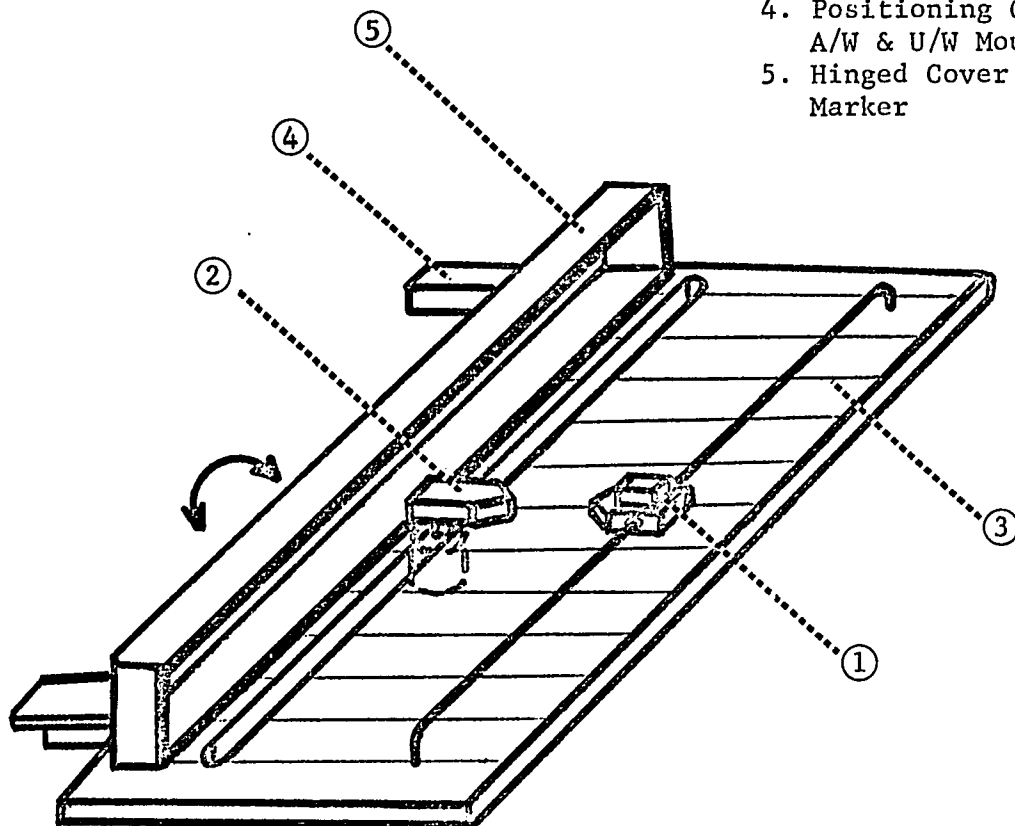


FIGURE 5

Schematic Drawing of SLIDE Apparatus

SLIDE device was movable, and was positioned both above the water (for pretest measures) and below the water (for adaptation measures). The above-water testing tank table and the underwater experimental table were fitted with tracks to position and hold the apparatus.

Three distances were presented to the S: 6, 12 and 18 inches from the edge of the board nearest the diver. The stimulus distances were presented in randomized block design with two sets of the three distances being presented on each administration. The S was instructed to return his marker to a starting position two to three inches from the edge of the board after each trial.

#### Adaptation Tasks

All Ss received the same tasks for the first 24 minutes underwater. Two tasks, found to be most effective in inducing adaptation from earlier pilot studies, were administered to all subjects in a balanced design. The adaptation tasks chosen were: a modified version of the Minnesota Rate of Manipulation Test, and an eye-hand task thought to maximize ballistic movement and provide meaningful feedback of arm movement.

The modified version of the Minnesota Rate of Manipulation Test (MRMT) was constructed of plexiglas for use underwater. The 60 plexiglas disks had red and black faces, and enough negative buoyancy to remain on the bottom of the pool (the buoyancy of the disks could have been greater, as sudden strong currents caused by rapid hand movements tended to shift them slightly).

Four standardized tasks were utilized: the placing, the turning (working hand only), the one-hand turning and placing, and the

displacing tasks (Educational Test Bureau, 1946). Each subtest was presented in a fixed sequence and individually timed. The sequence was repeated until 12 minutes of work was completed.

The modified MRMT was intended to assist in establishing a new afferent-efferent association. In order to perform this task one can use continuous visual feedback from the discrepancy between position of hand and desired location. However, since the subjects were instructed to finish the task as soon as possible, the assumption is that some ballistic movement in reaching across the various distances (6 to 24 inches) should be involved in order to complete the tasks.

The second adaptation device was built by the author to maximize feedback of reaching performance in a visually distorted environment, and was labeled the Underwater Distance Learning Apparatus (UDLA). It consisted of a gray-painted wooden platform 40 inches by 26 inches by 1/2 inch, resting on 10 inch legs. One hundred and five carriage bolts were loosely secured through a pattern of holes set 1-1/2 inches between centers, with 7 per row for 15 rows, beginning five inches from the Ss edge of the platform. The task consisted of the S moving to a prone position, stationing his chin above a reference line one inch in from the edge of the platform, and reaching underneath the device to displace a bolt pointed out by the E. The device was constructed to allow no visual feedback of hand movement (to minimize guiding) during reaching, but displacement of the target bolt provided a visual measure of reaching accuracy.

An average of 82 trials were presented during a 12 minute period of work, with the targets selected by the E. The E tended to give added

emphasis to those distances approximating the range of distances used on the testing device above water, to assure some practice at the distances being measured.

Since it is not possible to perform this task by visually guiding the hand, the S must issue efference relative to the distance of the chosen target; the usual afferent-efferent association appears inadequate to perform this task, due to the distorted visual input. Therefore, it was assumed that a new afferent-efferent association would be learned while performing the reaching movements. Adaptation was expected to be greatest for this task, since opportunity for discrepancy feedback was available to assist in learning of new afferent-efferent associations.

The possibility of order effects due to differential task effectiveness was minimized by balanced presentation of the adaptation tasks. Each task was to follow the other an equal number of times. (For one novice S the tasks were not presented in the appropriate sequence, resulting in an unbalanced presentation sequence for the adaptation tasks--this does not appear to have affected the results in any appreciable way.)

All tasks were administered in seven feet of water, in a large heated freshwater pool with light chlorination; the working site was 10 feet from the A-ETD. The contents of the pool were continually filtered and closely monitored, with resulting visibility in the pool being high and approximately constant through the experiment.

#### Experimental Tasks

After an initial 24 minutes of work on the adaptation tasks (interrupted by above water measurements) all divers participated in

an additional 12 minutes of work on two sets of "experimental" tasks. These short tasks were designed to provide similar distance reaching tasks while varying the type and amount of feedback in conflict with the visually distorted input. They were divided into experimental and control on the basis of the amount of visual conflict offered by the task.

The high feedback (experimental) group was required to place the visually distorted input in conflict with high reference cues such as view of own body and veridical measures of surround. The experimental (Hi feedback) tasks were:

- A. Body Reference - The S sat on a low stool in the deep end of the pool and reached for various body members (left and right thighs, knees, ankles and toes). Continued visual reference to the body was stressed, as was the need for ballistic movements. The diver was asked to first look at the body part indicated by the E (using a pointer and slate) and then reach quickly for the part indicated. No count was made of the number of trials; the task was continued for six minutes.
- B. Ground Reference Task - The S worked at a standing height table in the deep section of the pool. He was required to estimate the straight-line distance from a reference point one inch from the table edge to a designated target. Estimations were recorded by the S writing on a water-proof slate. The targets were a variety of common ocean shells, placed in designated spots by the E. After entering the estimated distance the diver retrieved the shell, and deposited it in a container. He then measured the distance from the reference dot to the previous location of the shell (marked by a small circle) with a ruler, and entered this figure opposite his first estimate. The divers completed an average of 12 such measurements in a six minute period.

The Lo veridical perception (control) group was presented with tasks equivalent in the amount and type of muscular activity and opportunity for ballistic reaching movements, but without equivalent body or surround referent feedback. The tasks were:

- A. N-Body Reference Task - Similar to the body reference task, except that the S worked at the underwater table, reaching for one of the eight lines placed at distances equivalent to those seen in the experimental condition. The control diver had the same opportunity for eye-hand coordinating movements, but no body conflict information. No count was made of the number of trials, but the task was continued for six minutes.
- B. N-Ground Reference Task - Similar to the experimental condition except that no distance measurements were performed. The S was required to make a second estimate after removing the shell. The average number of shells retrieved in the six minute period was higher for the control than the experimental Ss (15 to 12) since they had one fewer movement to make (measuring with the ruler being omitted).

Half the experienced and half the novice divers were assigned to the "Hi" feedback conditions, while half of each group performed "Lo" feedback tasks. A balanced presentation of task sequence was administered, with one exception.

### Procedure

Each S was instructed as to the nature of his tasks. Familiarization with the adaptation tasks consisted of a thorough description of each task and a brief practice session. The "Hi" and "Lo" experimental Ss also were informed of their body-reference and ground-reference tasks, but did not receive practice. As reminders, detailed instructions for the experimental tasks were placed on slates and shown to the Ss underwater.

Before each S went into the water he was instructed as to how to make the appropriate responses on the testing tank and SLIDE devices. He also was told to use only one hand (preferred or non-preferred, depending on the condition), and provided with a glove for the non-working hand as a reminder not to use that hand. The S was instructed

not to use the non-working hand at any time during the experiment other than during the above water measurements. The instructions stressed that the non-working hand had to be removed from the visual field both while working and while swimming to and from the testing apparatus. This was found to present little problem for the subjects.

All Ss were asked to wear facemasks supplied by the E (Sportsways No. 1628). Two Ss, unable to secure tight enough fits with the E's masks, were allowed to use their own. Each mask was checked to see that the faceplate was at the same approximate distance from the eye as the Sportsways mask.

Divers were provided with either a wet suit jacket or sweatshirt if they could not supply their own. The underwater tasks were not sufficiently difficult to provide high energy output, consequently there was ample opportunity for the cooler water to adversely affect performance. Several experienced divers chose not to use a protective garment, but they did not report any noticeable discomfort from loss of body heat. All divers were heavily weighted, so that neutral buoyancy should not have been a major factor in the establishment of new coordinating systems.

After initial measurements (pretests) at the A-ETD and the SLIDE, the S followed the E to the underwater table where he immediately re-took the SLIDE test to establish the initial effects of underwater distortion. Novice divers who were totally unfamiliar with SCUBA gear were first instructed in its use and allowed to breath through the regulator. After taking their pretest on the after-effect device and

SLIDE, they were given 5 to 10 minutes to adjust to the breathing apparatus while sitting in the shallow end of the pool. Any S given this adjustment period was instructed to avoid reaching for anything while underwater. They were carefully supervised to assure no opportunity for adaptation to occur before the underwater slide pre-test. All Ss then completed their series of two adaptation tasks interspersed with testing on the A-ETD and SLIDE. After 24 minutes the experimental tasks were administered, with after-effect testing after each six minutes. The SLIDE was administered again at the end of the 36 minutes of performing underwater.

Of the five occasions for testing on the A-ETD, the first and last testings consisted of five measurements of the target placed in the two settings of 7 and 14 inches from the facemask plate. The second, third and fourth testings were shortened to three measurements of the target at each of the two distances to avoid long above water delays. The first and fifth testings averaged approximately four minutes, while the middle three testings lasted for about 2-3/4 minutes.

Time underwater was chosen as the task variable rather than number of trials since it has been shown (Bowen, 1968) that cold adversely affects performance underwater, and degree of heat loss is related to time underwater. Ono and O'Reilly (1969) also noted that a "negative drift," producing an effect opposite to that produced by adaptation, could be recorded with increased time underwater. Thus, it was decided that time underwater would be the variable, with every attempt made to provide the same number of eye-hand coordination trials to the different experimental groups.

As previously mentioned, the index of adaptation chosen for the major variable, the above water measurements, was an after-effect rather than a simple measure of adaptation (as in the SLIDE). Use of the after-effect as the index for adaptation should minimize the effect of conscious correction and any demand characteristics present in the experimental situation.

#### Experimental Design

The experimental design for the after-effect testing can be summarized in Table 1. The design was identical for experienced and novice divers, and required two sets of testing measurements, one for the working hand and another for the non-working hand. The SLIDE measurement sequence is summarized in the right column of Table 1. Only the working hand was used on this device.



## CHAPTER III

### RESULTS

In analyzing the results, a distinction was made between performance on the after-effect testing device (A-ETS), providing measures of after-effect upon removal of the abnormal visual input, and that on the SLIDE apparatus, designed to directly measure adaptation to distance distortion in the U/W environment. A minimum acceptable significance level of  $P < .05$  was set for all statistical tests. All t-tests are two-tailed.

#### After-Effect Analysis

The basic data for testing hypotheses having after-effect measurements as the dependent variable (Hypotheses 1-10) are the mean scores derived for the working and non-working hands during the five testings on the A-ETD. Each of the mean scores is derived from three (or five) measures of apparent distance from each hand at one of two stimulus distances (7 and 14 inches).

Separate analyses were performed on the results from the adaptation period (the first 24 minutes of the U/W performance--providing measures at 12 minutes and 24 minutes), and those from the experimental period (the last 12 minutes of U/W performance--with testings at 30 minutes and 36 minutes). The after-effect data are expressed as difference scores, calculated as change from the initial pretest measurements; positive values represent over-reach from pretest. Each data point was derived from an average of 16 subjects within each of the two experience groups,

Hi and Lo feedback Ss received identical tasks throughout the first 24 minutes.

No significant difference was found on any of the 24 't' comparisons testing difference scores on the 7 and 14 inch target placements within each experience group and hand condition (Tables 2 and 3), allowing for averaging of after-effect measures across distances to increase score stability. All analyses were performed with mean difference scores averaged across the two distances.

Adaptation Period. The magnitude of the adaptive responses, and their change over time for the testing sessions immediately following the presentation of the adaptation tasks, can be observed in Figure 6. The data are expressed as over-reach from the initial pretest scores, with responses recorded after 12 and 24 minutes of practice underwater.

A 2 (Experience) X 2 (Hand) X 2 (Time U/W) analysis of variance with repeated measures on the last two factors (Lindquist Type VI, 1956; Winer Case I, 1962) was performed on the adaptation period data. The results of the analysis are summarized in Table 4. Further breakdown of the data was accomplished by two additional three-factor mixed-model analyses of variance, providing tests of main effects within the experienced and novice groups. Tables 5 and 6 summarize the results of these designs contrasting Hi and Lo feedback groups with working and non-working hand and time U/W.

Results from Table 4, contrasting experienced and novice Ss indicated a significant difference in the amount of adaptation exhibited by the experienced Ss compared to the novice Ss ( $F(1,39) = 7.29$ ,  $p < .025$ ). This effect is partially the result of a significant

TABLE 2

t-Test Comparisons of Target Distance  
 Using Adaptation Session Difference Scores  
 By Experience Groups

Experience Group	Hand	Time (min.)	Mean (7 inch)	Mean (14 inch)	t (df=15)	p	
Experienced	Working	12	1.18	1.41	0.79	ns	
		24	1.88	1.92	0.26	ns	
	Non-Working	12	1.05	0.86	0.75	ns	
		24	1.54	1.59	0.23	ns	
	Novice	Working	12	0.99	1.09	0.43	ns
			24	1.26	0.97	1.35	ns
Non-Working		12	0.20	0.35	0.81	ns	
		24	0.25	0.45	0.99	ns	

TABLE 3

t-Test Comparisons of Target Distance  
Using Experimental Session Difference Scores  
By Experience and Feedback Groups

Experience Group	Feedback Group	Hand	Time (min.)	Mean (7 in.)	Mean (14 in.)	t (df=7)	p	
Experienced	Hi	Working	30	1.58	2.00	1.34	ns	
			36	1.57	2.06	1.36	ns	
	Feedback	Non-Working	30	2.11	2.06	0.13	ns	
			36	2.34	2.08	0.40	ns	
	Lo	Working	30	1.51	1.21	0.64	ns	
			36	1.46	1.51	0.11	ns	
		Feedback	Non-Working	30	1.12	1.15	0.14	ns
				36	0.98	1.31	1.00	ns
Novice	Hi	Working	30	1.15	1.18	0.12	ns	
			36	1.46	1.22	1.10	ns	
	Feedback	Non-Working	30	0.80	0.28	1.82	ns	
			36	0.55	0.04	1.65	ns	
	Lo	Working	30	1.26	1.31	0.20	ns	
			36	1.61	1.81	1.04	ns	
		Feedback	Non-Working	30	0.65	0.73	0.29	ns
				36	0.94	1.41	1.53	ns

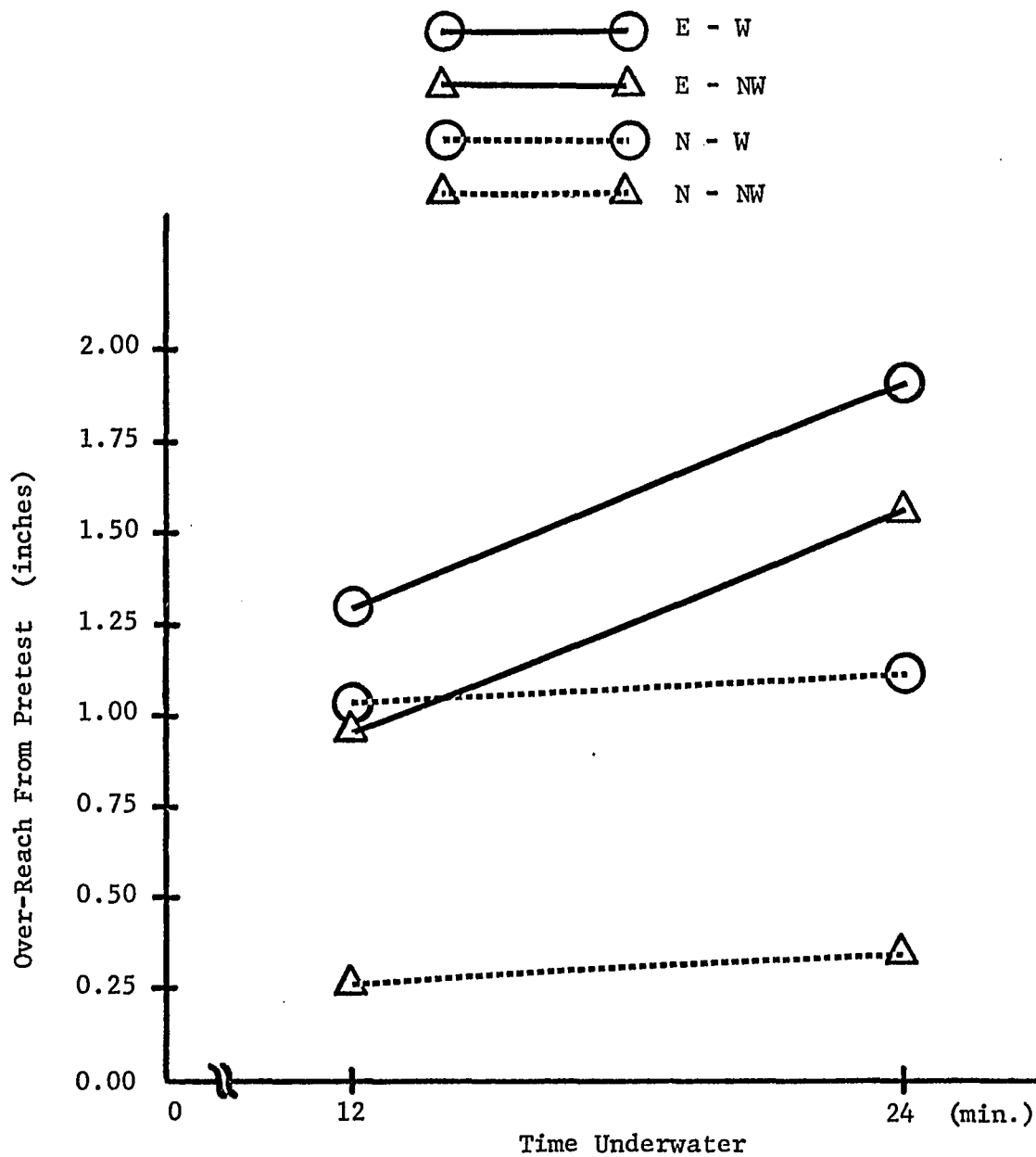


FIGURE 6

Comparison of Amount of Adaptation  
 By Working and Non-Working Hands -  
 For Experienced and Novice Ss  
 During Adaptation Phase

TABLE 4

Summary of Analysis of Variance  
 On Adaptation Period Difference Scores  
 Experience X Hand X Time

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Experience (A)	1	17.31	7.29	.025
Error (AXS) <sub>w</sub>	30	2.37		
Within Subjects				
Hand (B)	1	9.74	18.05	.001
AXB	1	1.42	2.63	ns
Error (BXS) <sub>w</sub>	30	0.54		
Time (C)	1	3.71	14.39	.001
AXC	1	2.27	8.79	.01
Error (CXS) <sub>w</sub>	30	0.26		
BXC	1	0.00	0.00	ns
AXBXC	1	0.00	0.00	ns
Error (BCXS) <sub>w</sub>	30	0.19		
Total	127			

TABLE 5

Summary of Analysis of Variance  
 On Adaptation Period Difference Scores  
 Feedback Group X Hand X Time  
 Experienced Subjects

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Feedback (A)	1	2.37	0.71	ns
Error (AXS) <sub>w</sub>	14	3.31		
Within Subjects				
Hand (B)	1	1.86	4.36	ns
AXB	1	0.24	0.57	ns
Error (BXS) <sub>w</sub>	14	0.43		
Time (C)	1	5.89	18.41	.001
AXC	1	0.31	0.96	ns
Error (CXS) <sub>w</sub>	14	0.32		
BXC	1	0.00	0.00	ns
AXBXC	1	0.18	0.91	ns
Error (BCXS) <sub>w</sub>	14	0.20		
Total	63			

TABLE 6

Summary of Analysis of Variance  
 On Adaptation Period Difference Scores  
 Feedback Group X Hand X Time  
 Novice Subjects

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Feedback (A)	1	3.04	2.18	ns
Error (AXS) <sub>w</sub>	14	1.39		
Within Subjects				
Hand (B)	1	9.30	14.17	.01
AXB	1	0.78	1.19	ns
Error (BXS) <sub>w</sub>	14	0.66		
Time (C)	1	0.09	0.43	ns
AXC	1	0.08	0.39	ns
Error (CXS) <sub>w</sub>	14	0.20		
BXC	1	0.00	0.00	ns
AXBXC	1	0.06	0.31	ns
Error (BCXS) <sub>w</sub>	14	0.20		
Total	63			

difference between the amount of adaptation registered for the working and non-working hands of the novice Ss ( $F(1.14) = 14.17$ ,  $p. < .01$ , Table 6). There was no comparable difference between the working and non-working hand performances exhibited by the experienced Ss (Table 5).

Tests of significance (t-tests) between the distance estimation scores for 12 and 24 minute testings and those registered on the pretest are summarized in Table 7, for working and non-working hands of both novice and experienced Ss. All working and non-working mean scores were significantly greater than pretest for the experienced group, while only the working hand results were significantly above the initial settings for the novices. Novice non-working hand results did not significantly differ from chance responding from the pretest level.

As a result of these analyses, Hypothesis 1, predicting an adaptive shift in responses for both working and non-working hands for the experienced Ss, was accepted. Hypothesis 2, predicting a difference in adaptive responding for the working and non-working hands of the novice Ss, was also accepted.

After 12 minutes of U/W work there was no difference between the after-effect exhibited by the working hand of the novice and that found for the working and non-working hands of the experienced S. After 24 minutes this relationship changes; a significant 't' was found between the working hand scores of the experienced and novice Ss ( $t(30) = 2.68$ ,  $p < .02$ ). The difference between the novice Ss working hand measurements and the non-working hand measurements of the experienced Ss was not significant at the 24 minute testing session.

TABLE 7

Summary of t-Tests Between  
Adaptation Period Scores and Pretest  
By Experience Groups

Experience Group	Hand	Time (Min.)	Mean Diff. Score From Pretest (In.)	t (df=15)	p
Experienced	Working	12	1.30	4.65	.001
		24	1.90	9.53	.001
	Non-Working	12	0.95	3.77	.01
		24	1.29	5.53	.001
Novice	Working	12	1.04	4.55	.001
		24	1.11	5.12	.001
	Non-Working	12	0.27	1.57	ns
		24	0.36	2.04	ns

Since the experienced S exhibited greater adaptation than the novice at the 24 minute testing with his working hand, and at both testings with his non-working hand, Hypothesis 3 was accepted, with the reservation that initial (12 minute) measures of working hand adaptation did not differ for the two experience groups.

Significant changes in amount of adaptation over time were found for the experienced Ss ( $F(1,14) = 18.41, p < .001$ , Table 5), but not for the novices (Table 6). Supplementary t-tests revealed that the significant Experience X Time interaction in Table 4 was due to this change in amount of adaptation over time for the experienced Ss ( $t(15) = 3.57, p < .01$ ), for working hand measures;  $t(15) = 3.22, p < .01$ , for non-working hand measures); with no change in amount of adaptation over time for the novices.

Adaptation period data does not completely support Hypothesis 4, since increased adaptation occurred only for the experienced Ss, not for the novices.

The secondary analyses of variance (Tables 5 and 6), within experience groups, provided a check on the effectiveness of randomization of Ss within feedback conditions. Neither analysis showed a significant difference in responding between the subjects destined to receive the experimental and control feedback conditions.

Experimental Period. To adequately portray change in adaptation occurring after the introduction of the experimental conditions, data for this period was analyzed as difference scores from the after-effect measurements registered at the end of the 24 minute adaptation period. Figures 7 and 8 illustrate this change in over-reach for the last

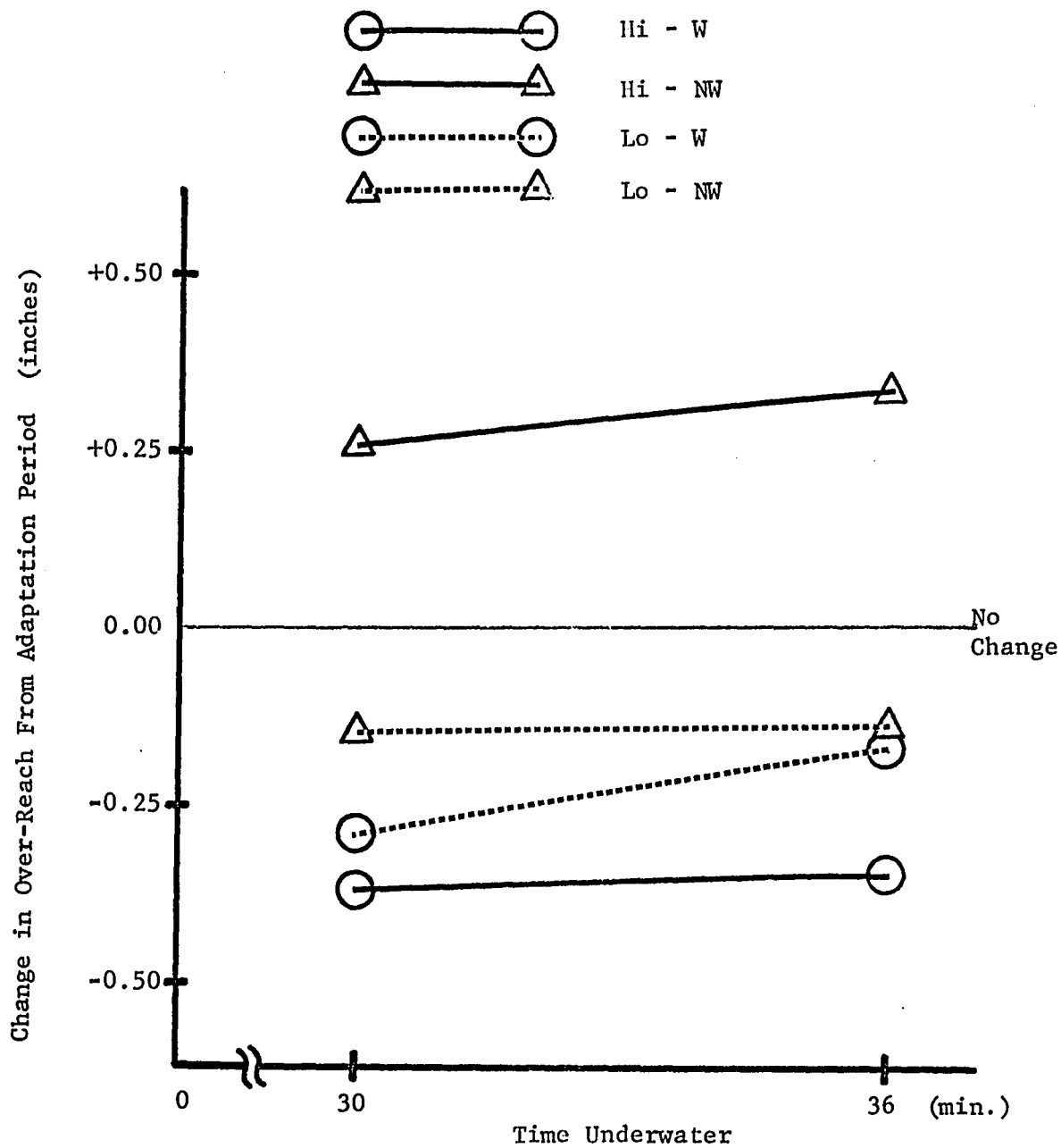


FIGURE 7  
 Comparison of Change in After-effect  
 By Working and Non-Working Hands  
 Hi and Lo Feedback Subjects  
 Experienced Group

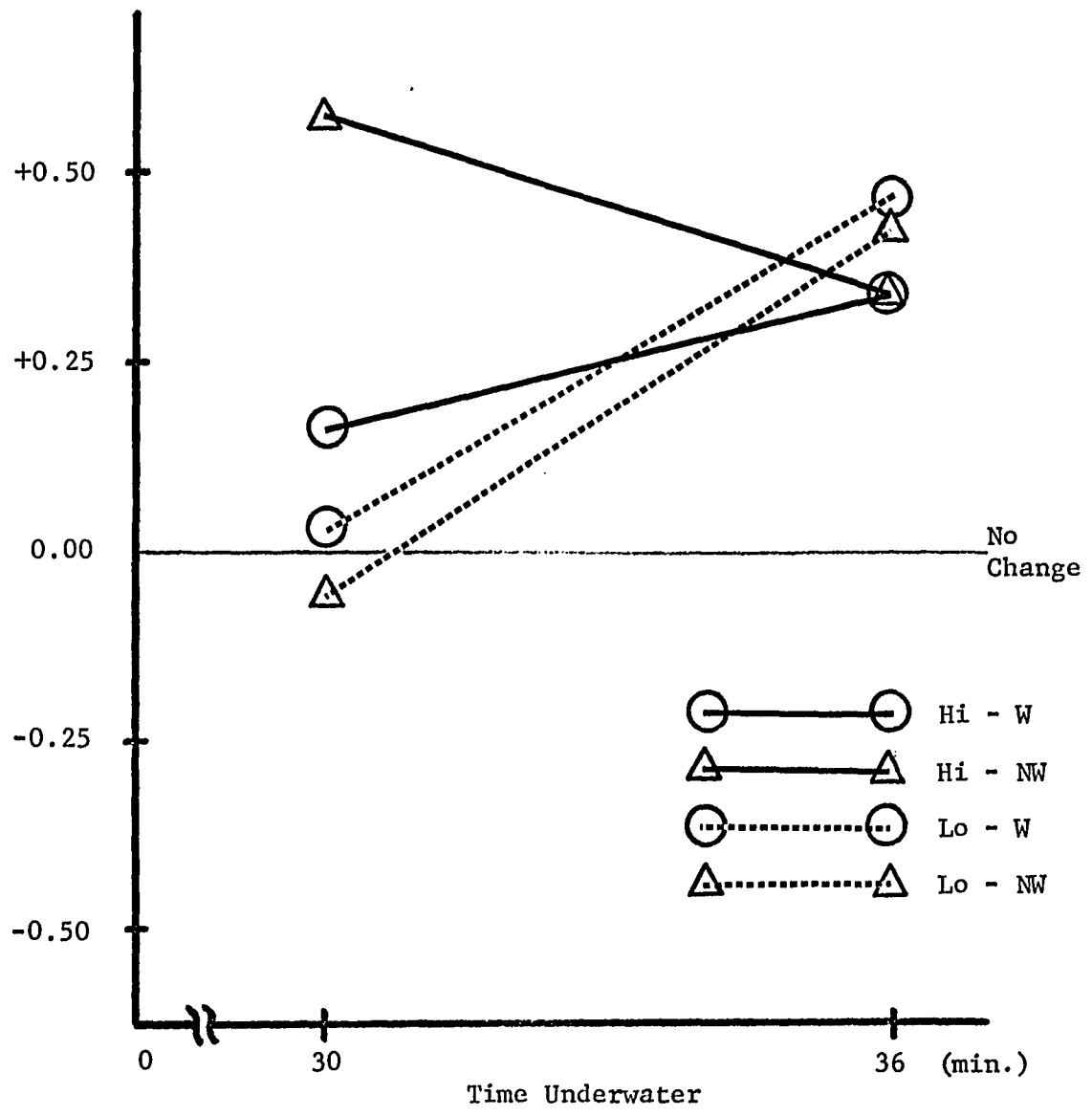


FIGURE 8  
Comparison of Change in After-effect  
By Working and Non-Working Hands  
Hi and Lo Feedback Subjects  
Novice Group

testing of the adaptation session, for the working and non-working hand measurements of the Hi and Lo feedback groups within each experimental condition. Novice Ss generally registered a positive change in adaptation during the experimental session (Figure 8); the experienced groups, with the exception of the non-working hand of the Hi feedback Ss, demonstrated slightly less adaptive responding during the last 12 minutes of after-effect testing (Figure 7).

A 2 (Experience) X 2 (Hand) X 2 (Time) analysis of variance (Winer Case I) on the data received from the 30 and 36 minute testings, found no significant difference between any of the main effects or interactions, indicating stable responding across adaptation and experimental phases of the investigation (Table 8).

The novice and experimental groups were separately analyzed (Tables 9 and 10), contrasting Feedback Condition (Hi - Lo) X Hand (Working - Non-working) X Time (30 - 36 min.). Analysis of the feedback group responses within experienced Ss found a significant difference between working and non-working hand responses ( $F(1,14) = 9.99, p < .01$ , Table 9), and a significant Feedback X Hand interaction ( $F(1,14) = 6.19, p < .05$ , Table 9). Both measures reflect the significant difference between Hi feedback Ss' non-working and working hand responses noted in Figure 7, with the non-working responses significantly greater at both the 30 and 36 minute testings ( $t(7) = 2.87, p < .05$ ) at 30 min.;  $t(7) = 3.77, p < .01$ , at 36 min.).

An additional Feedback X Hand X Time Case I analysis of variance was performed on responses of Hi and Lo feedback Ss within the novice group. As can be noted from Table 10, only the Feedback X Time

TABLE 8

Summary of Analysis of Variance  
On Experimental Period Difference Scores  
Experience X Hand X Time

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Experience (A)	1	5.28	3.81	ns
Error (AXS) <sub>w</sub>	30	1.39		
Within Subjects				
Hand (B)	1	1.43	3.84	ns
AXB	1	0.72	1.93	ns
Error (BXS) <sub>w</sub>	30	0.37		
Time (C)	1	0.56	1.64	ns
AXC	1	0.18	0.54	ns
Error (CXS) <sub>w</sub>	30	0.34		
BXC	1	0.09	0.40	ns
AXBXC	1	0.04	0.19	ns
Error (BCXS) <sub>w</sub>	30	0.22		
Total	127			

TABLE 9

Summary of Analysis of Variance  
 On Experimental Period Difference Scores  
 Feedback Group X Hand X Time  
 Experienced Subjects

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Feedback (A)	1	0.39	0.21	ns
Error (AXS) <sub>w</sub>	14	1.82		
Within Subjects				
Hand (B)	1	2.08	9.99	.01
AXB	1	1.29	6.19	.05
Error (BXS) <sub>w</sub>	14	0.21		
Time (C)	1	0.05	0.11	ns
AXC	1	0.00	0.00	ns
Error (CXS) <sub>w</sub>	14	0.48		
BXC	1	0.00	0.03	ns
AXBXC	1	0.03	0.19	ns
Error (BCXS) <sub>w</sub>	14	0.15		
Total	63			

TABLE 10

Summary of Analysis of Variance  
 On Experimental Period Difference Scores  
 Feedback Group X Hand X Time  
 Novice Subjects

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
Between Subjects				
Feedback (A)	1	0.26	0.23	ns
Error (AXS) <sub>w</sub>	14	1.10		
Within Subjects				
Hand (B)	1	0.06	0.13	ns
AXB	1	0.34	0.73	ns
Error (BXS) <sub>w</sub>	14	0.47		
Time (C)	1	0.69	3.88	ns
AXC	1	0.97	5.43	.05
Error (CXS) <sub>w</sub>	14	0.18		
BXC	1	0.13	0.41	ns
AXBXC	1	0.23	0.76	ns
Error (BCXS) <sub>w</sub>	14	0.31		
Total	63			

interaction was significant ( $F(1,14) = 5.43, p < .05$ ), partially reflected in an improvement in adaptive responding over time for the Lo feedback Ss concomitant with a slight decline in average Hi feedback responding. The interaction was also affected by a significant difference in non-working hand performance between Hi and Lo feedback Ss ( $t(14) = 2.53, p < .05$ ) at 30 minutes, dropping to a non-significant difference at 36 minutes. No other main effect of interaction was significant.

A summary of t-tests between adaptation scores registered during the experimental session and those provided after 24 minutes of practice with the adaptation tasks reflect only two significant changes in after-effect responding (Table 11). The 30 minute responses for the Hi feedback novices on their non-working hand were significantly above their adaptation period performance ( $t(7) = 2.65, p < .05$ ). A significant decline in distance estimation scores was noted for the Hi feedback experienced Ss at the 30 minute testing ( $t(7) = 2.48, p < .05$ ). None of the other changes in after-effect were significantly different from chance responding (Table 11).

Since the non-working hand exhibited a significant positive change in adaptation for the Hi feedback experienced Ss, Hypothesis 5, predicting increased adaptation for experimental Ss, was tentatively accepted, pending elaboration in the discussion. With the non-working hand of the Hi feedback novice Ss producing a significant increase in positive after-effect, and all trends in the predicted direction, Hypothesis 6 was accepted with some reservation concerning the magnitude of the effect. Based on the lack of significance noted on Lo feedback

TABLE 11  
 Summary of t-Tests Between  
 Experimental Scores and Adaptation  
 Level at End of 24 Minutes U/W  
 By Experience and Feedback Groups

Experience Group	Feedback Group	Hand	Time (Min.)	Mean Diff. Score From 24 Min. (In.)	t (df=7)	p
Experienced	Hi Feedback	Working	30	-0.37	2.48	.05
			36	-0.35	0.85	ns
		Non-Working	30	0.26	0.98	ns
			36	0.33	0.77	ns
	Lo Feedback	Working	30	-0.29	2.14	ns
			36	-0.17	0.79	ns
		Non-Working	30	-0.15	0.89	ns
			36	-0.14	0.39	ns
Novice	Hi Feedback	Working	30	0.17	0.66	ns
			36	0.34	1.50	ns
		Non-Working	30	0.58	2.65	.05
			36	0.34	1.29	ns
	Lo Feedback	Working	30	0.03	0.17	ns
			36	0.47	1.54	ns
		Non-Working	30	-0.06	0.44	ns
			36	0.43	1.17	ns

responses (Table 11), Hypothesis 7, predicting a constant level of performance for control Ss was accepted, although trends were not in the predicted direction.

Adaptation Period Task Analysis. Implementation of the UDLA was expected to increase adaptation over that noted for the MRMT, since the former provided the greatest opportunity for ballistic movement. Table 12 provides for comparison of the effectiveness of each task in increasing after-effect responding, with entries reflecting amount of change in adaptation noted with introduction of the specific task. For experienced Ss receiving the UDLA during the first 12 minute U/W session, an average increase of 1.69 inches was noted at the first testing session for working hand scores, and 1.28 inches for non-working hand scores. Experienced Ss receiving the MRMT first demonstrated responses of 0.90 inches of over-reach for the working hand and 0.62 inches for the non-working hand. The UDLA also tended to evoke greater adaptation than MRMT for those Ss receiving it as the second task (0.85 to 0.36 inches working hand; 0.70 to 0.52 inches non-working hand). No significant difference was noted in after-effect scores for novices relative to the various practice tasks.

Although the results are in the predicted direction, no significant difference was noted in after-effect scores for novices relative to the various practice tasks.

Although the results are in the predicted direction, no significant differences were found on 't' comparisons for effectiveness of the various tasks, so that Hypothesis 8 was rejected.

TABLE 12

Mean Changes in Apparent Distance  
 For Adaptation Tasks  
 By Experience Group and Hand

Experience Group	Task	First Testing		Second Testing	
		Working Hand	Non-Working Hand	Working Hand	Non-Working Hand
Experienced	UDLA	1.69	1.28	0.85	0.70
	MRMT	0.90	0.62	0.36	0.52
Novice	UDLA	1.06	0.41	-0.09	0.28
	MRMT	1.02	0.17	0.28	-0.19

Experimental Period Task Analysis. Comparison of effectiveness in inducing change in adaptation was measured for the two experimental and two control tasks used in the experimental session. Summaries of the amount of adaptive change registered for either hand on first and second presentation of the various tasks is summarized in Table 13. None of the mean score comparisons across tasks and conditions were significant, causing Hypothesis 9 to be rejected.

After-effect Magnitude Related to Target Distance. Table 2 and Table 3 summarize a series of t-tests between the absolute magnitude of responses on the 7 and 14 inch target placements; none of these differences were significant, nor was there a noticeable trend in responses for the two distances. Hypothesis 10, predicting a proportional increase in absolute magnitude of over-reach with distance, was not supported.

#### SLIDE Analysis

Hypotheses 11 - 14 were based on results secured from distance estimations on an U/W task. The dependent variable is the mean of two trials at each of three distances (6, 12 and 18 inches) for five administrations (above water pretest (A/W Pretest), under water pretest (U/W Pretest), 12 min., 24 min., 36 min. U/W testings). Mean scores are based on 13 Ss in each experience group, 3 Ss in each group having missing data. No significant differences were found on performance between Hi and Lo feedback groups on the one affected measure (36 min. testing), enabling the data to be presented only by experience group.

When tested immediately after entering the pool (U/W Pretest), both experienced and novice Ss exhibited a decrease in accuracy of

TABLE 13

## Mean Changes in Apparent Distance

## For Experimental Tasks

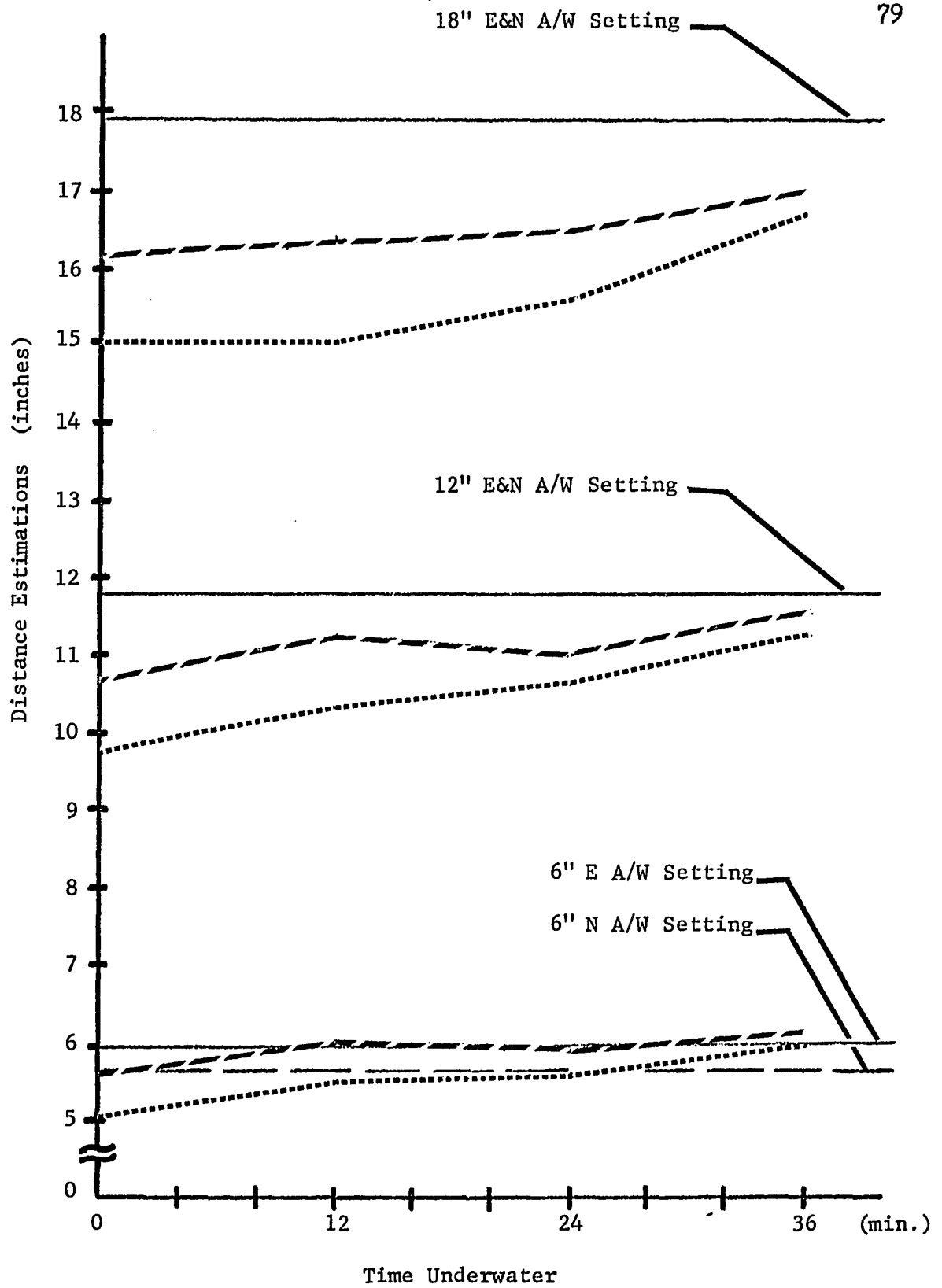
By Experience Group, Feedback Condition, and Hand

Experience Group	Feedback Condition	Task	First Testing		Second Testing	
			Working Hand	Non-Working Hand	Working Hand	Non-Working Hand
Experienced	Hi	Shell	-1.10	0.36	-0.08	-0.25
		Body	-0.63	0.14	0.12	0.40
	Lo	Shell	-0.48	-0.36	0.28	0.29
		Body	-0.10	0.06	-0.02	-0.28
Novice	Hi	Shell	0.02	0.34	0.20	-0.46
		Body	0.32	0.84	0.14	-0.04
	Lo	Shell	-0.13	-0.07	0.31	0.94
		Body	0.39	-0.03	0.49	0.21

matching the distance of the target, relative to their performance in air. Figure 9 delineates the drop in accuracy, and subsequent improvement, of distance matching for all three stimulus distances utilized (6, 12 and 18 inches), for both the experienced and novice groups. A series of treatment-by-subjects analyses of variance were performed on the SLIDE data collection during the A/W Pretest, the U/W Pretest, and testing after three 12 minute U/W work sessions. A number of range tests were applied to these sets of data, using the Newman-Keuls technique (Winer, 1962).

For the 6 inch target setting the experienced and novice Ss both showed a significant effect across the five test administrations ( $F(4,48) = 3.08, p < .05$ , Table 14A;  $F(4,48) = 4.64, p < .01$ , Table 15A). The analysis of variance and Newman-Keuls range statistic are summarized for the experienced Ss 6 inch measurements in Table 14B, which indicates that the U/W pretest did not differ from the A/W pretest beyond a chance level (of all the analyses this was the only A/W pretest - U/W pretest comparison that was insignificant). There was a gradual increase in distance estimations from the U/W pretest through the 36 minute testing; the 24 and 36 minute mean settings were found to be significantly greater than the initial U/W pretest.

Distance estimations by the novices for the 6 inch target placement followed that of the experienced Ss, with the exception that the initial U/W pretest was significantly lower than the A/W pretest. Significantly improved performance was noted for the 12, 24 and 36 minute settings, relative to the U/W pretest (Table 15B).



----- Experienced (E)  
 ..... Novice (N)

FIGURE 9

Distance Estimations  
 From SLIDE Apparatus

TABLE 14 A

Analysis of Variance Summary Table for SLIDE  
Experienced Subjects on 6" Target Placement

Source	df	MS	F	p
SLIDE Tests	4	0.62	3.08	.05
Subjects	12	1.65	-	
TXS	48	0.20	-	
Total	64			

TABLE 14 B

Newman-Keuls Range Statistic  
Mean Scores for Experienced Subjects  
On 6" Target Placement

	U/W Pretest	12 Min.	A/W Pretest	24 Min.	36 Min.
Mean Score	5.58	5.89	5.98	6.06	6.15
U/W Pretest	-	-	-	*	*
12 Min.		-	-	-	-
A/W Pretest			-	-	-
24 Min.				-	-
36 Min.					-

\*  $p < .05$

TABLE 15 A

Analysis of Variance Summary Table for SLIDE  
Novice Subjects on 6 " Target Placement

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
SLIDE Tests	4	1.41	4.64	.01
Subjects	12	7.13	-	
TXS	48	0.30	-	
Total	64			

TABLE 15 B

Newman-Keuls Range Statistic  
Mean Scores for Novice Subjects  
On 6" Target Placement

	U/W Pretest	12 Min.	A/W Pretest	24 Min.	36 Min.
Mean Score	5.05	5.52	5.64	5.65	5.96
U/W Pretest	-	*	*	*	**
12 Min.		-	-	-	-
A/W Pretest			-	-	-
24 Min.				-	-
36 Min.					-

\* p < .05

\*\* p < .01

Both the experienced and novice Ss demonstrated a highly significant loss in distance matching accuracy from the air pretest to the initial U/W pretest for the 12 inch target placement (Tables 16 and 17). For the novice group all of the underwater settings were significantly different from the A/W pretest, with only the 36 minute setting showing a level of significance less than .01 (Table 17B). For the experienced Ss the U/W pretest and the 24 minute setting were significantly different ( $p < .01$ ) from the air pretest; the 12 minute setting was only slightly less significantly different ( $p < .05$ ). The 36 minute setting was not significantly different from the air pretest (Table 16B).

Very significant losses in accuracy of distance estimation occurred from the air measurements to the water measurements for responses to the SLIDE target set at 18 inches. As in the 12 inch analyses, the treatment-by-subjects analyses of variance for the 18 inch measures revealed very significant effects within the five administrations ( $F(4,48) = 16.20, p < .001$ , for the experienced Ss;  $F(4,48) = 33.26, p < .001$ , for the novice Ss). The summary of the Newman-Keuls tests for the experienced Ss (Table 18B) and the novice Ss (Table 19B) indicated that the first three underwater test administrations produced distance estimations significantly lower ( $p < .01$ ) than those found for the final U/W testing (after 36 minutes of U/W practice).

Although both experience groups demonstrated significant improvement in performance over time underwater, the final (36 min.) testing

Both the experienced and novice Ss demonstrated a highly significant loss in distance matching accuracy from the air pretest to the initial U/W pretest for the 12 inch target placement (Tables 16 and 17). For the novice group all of the underwater settings were significantly different from the A/W pretest, with only the 36 minute setting showing a level of significance less than .01 (Table 17B). For the experienced Ss the U/W pretest and the 24 minute setting were significantly different ( $p < .01$ ) from the air pretest; the 12 minute setting was only slightly less significantly different ( $p < .05$ ). The 36 minute setting was not significantly different from the air pretest (Table 16B).

Very significant losses in accuracy of distance estimation occurred from the air measurements to the water measurements for responses to the SLIDE target set at 18 inches. As in the 12 inch analyses, the treatment-by-subjects analyses of variance for the 18 inch measures revealed very significant effects within the five administrations ( $F(4,48) = 16.20, p < .001$ , for the experienced Ss;  $F(4,48) = 33.26, p < .001$ , for the novice Ss). The summary of the Newman-Keuls tests for the experienced Ss (Table 18B) and the novice Ss (Table 19B) indicated that the first three underwater test administrations produced distance estimations significantly lower ( $p < .01$ ) than those found for the final U/W testing (after 36 minutes of U/W practice).

Although both experience groups demonstrated significant improvement in performance over time underwater, the final (36 min.) testing

TABLE 16 A

Analysis of Variance Summary Table for SLIDE  
Experienced Subjects on 12" Target Placement

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
SLIDE Tests	4	2.45	7.07	.001
Subjects	12	5.27	-	
TXS	48	0.35	-	
Total	64			

TABLE 16 B

Newman-Keuls Range Statistic  
Mean Scores for Experienced Subjects  
On 12" Target Placement

	U/W Pretest	24 Min.	12 Min.	36 Min.	A/W Pretest
Mean Score	10.71	11.01	11.26	11.56	11.81
U/W Pretest	-	-	*	**	**
24 Min.		-	-	*	**
12 Min.			-	-	*
36 Min.				-	-
A/W Pretest					-

\*  $p < .05$

\*\*  $p < .01$

TABLE 17 A

Analysis of Variance Summary Table for SLIDE  
Novice Subjects on 12" Target Placement

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
SLIDE Tests	4	8.09	18.31	.001
Subjects	12	3.69	-	
TXS	48	0.44	-	
Total	64			

TABLE 17 B

Newman-Keuls Range Statistic  
Mean Scores for Novice Subjects  
On 12" Target Placement

	U/W Pretest	12 Min.	24 Min.	36 Min.	A/W Pretest
Mean Score	9.78	10.35	10.66	11.28	11.79
U/W Pretest	-	*	**	**	**
12 Min.		-	-	*	**
24 Min.			-	*	**
36 Min.				-	*
A/W Pretest					-

\*  $p < .05$

\*\*  $p < .01$

TABLE 18 A

Analysis of Variance Summary Table for SLIDE  
Experienced Subjects on 18" Target Placement

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
SLIDE Tests	4	6.13	16.20	.001
Subjects	12	5.05	-	
TXS	48	0.38	-	
Total	64			

TABLE 18 B

Newman-Keuls Range Statistic  
Mean Scores for Experienced Subjects  
On 18" Target Placement

	U/W Pretest	12 Min.	24 Min.	36 Min.	A/W Pretest
Mean Score	16.15	16.35	16.49	16.99	17.86
U/W Pretest	-	-	-	**	**
12 Min.		-	-	**	**
24 Min.			-	**	**
36 Min.				-	**
A/W Pretest					-

\*  $p < .05$

\*\*  $p < .01$

TABLE 19 A

## Analysis of Variance Summary Table for SLIDE

## Novice Subjects on 18" Target Placement

<u>Source</u>	<u>df</u>	<u>MS</u>	<u>F</u>	<u>p</u>
SLIDE Tests	4	19.09	33.26	.001
Subjects	12	5.13	-	
TXS	48	0.57	-	
Total	64			

TABLE 19 B

## Newman-Keuls Range Statistic

## Mean Scores for Novice Subjects

## On 18" Target Placement

	U/W Pretest	12 Min.	24 Min.	36 Min.	A/W Pretest
Mean Score	15.08	15.10	15.64	16.70	17.91
U/W Pretest	-	-	-	**	**
12 Min.		-	-	**	**
24 Min.			-	**	**
36 Min.				-	**
A/W Pretest					-

\* p &lt; .05

\*\* p &lt; .01

still produced estimations significantly lower than the A/W pretest-- indicating less than adequate adaptation at this greater distance.

Performance on the SLIDE apparatus provided somewhat conflicting results for the various target distances used. Acceptance or rejection of stated hypotheses was based on what appeared to be the "general" case considering all of the distance fluctuations.

Hypothesis 11, predicting less error on initial U/W pretests for experienced Ss as compared to novice Ss, was tested with a series of 't' comparisons (Table 20). No significant difference in magnitude of under-estimation was found between novices and experiences Ss on the 6 inch condition, while at the greater distances the results were in the predicted direction, with experienced Ss exhibiting significantly less change from A/W pretest to U/W pretest, supporting Hypothesis 11.

Significant adaptation was noted over time for all target distances for each experience group (as noted in the Newman-Keuls tests presented above), allowing Hypothesis 12 to be unequivocally accepted.

Hypothesis 13 was rejected on the basis that neither group demonstrated fully adapted responding for either the 12 or 18 inch target placements, with no significant difference noted between groups on the final (36 min.) measurements.

The absolute magnitude of under-estimation from A/W pretest distances at U/W pretest (Table 20) was found to vary with target distance from the S, supporting Hypothesis 14. For the 6 inch condition under-estimation was 0.40 inches for experienced Ss, and 0.59 inches for novice Ss. For the 12 inch condition, novices under-estimated the target by 2.01 inches, as compared to an error of 1.10 inches for the

TABLE 20

Summary of t Comparisons for  
 Experienced and Novice Group Means  
 On U/W Pretest Difference Scores from A/W Pretest

Target Placement	Experienced U/W Pretest Mean Diff. (inch)	Novice U/W Pretest Mean Diff. (inch)	t	p
6 inch	-1.40	-0.59	0.78	ns
12 inch	-1.10	-2.01	2.59	.02
18 inch	-1.71	-2.83	2.42	.05

experienced Ss. Underestimations of 2.83 inches and 1.71 inches were noted for novice and experienced Ss, respectively.

## CHAPTER IV

### DISCUSSION

Results from the adaptation phase of the after-effect analysis revealed that after 12 minutes of U/W psychomotor performance, the novice diver responded to the distorted visual input by initiating a new afferent-efferent coordinating system with his working hand, allowing him to reach a level of adaptive responding significantly above his pretest measures, and equal to that of the experienced divers. Apparently the restructuring that occurred for the novice differed from that experienced by the more expert divers, since the latter group continued to adapt with time, while the novices performed at the same level after double the amount of practice.

Additional evidence that the novice and experienced divers employed different restructuring systems was manifested when adaptation measures for the working and non-working hands were compared. The experienced diver registered adaptation equally with both hands; the novice diver, in contrast, demonstrated very significantly lower amounts of adaptation with his non-working hand relative to his working hand. Adaptation registered for the novice diver's non-working hand failed to be significantly better than chance during both the 12 and 24 minute testings, indicating no intermanual transfer from the adapted working hand. Performance of the experienced divers on the after-effect testing device was indicative of that labeled visual adaptation, while novice divers demonstrated typical proprioceptive adaptation.

The experimental tasks were implemented to increase the possibility of adaptation through visual restructuring due to the selective presentation of input stimuli in conflict with selected veridical referents. Since the experienced Ss appeared to function from the onset with a change in visual coding, no dramatic change in performance would be expected due to the introduction of the experimental conditions. On the other hand, the novice diver appeared to have functioned through the adaptation period with an altered felt-position of the hand, or change in coding in the more primitive proprioceptive sense. Introduction of the Hi and Lo feedback conditions should have provided the greatest opportunity for shift to visual recoding for these subjects.

Considering this performance on the initial adaptation trials, a post hoc interpretation of performance during the experimental session followed a pattern consistent with the stated hypotheses. Evaluation of the responses to the experimental tasks based on the level of adaptation attained by the 24 minute testing is consistent with the fact that Hi feedback experienced divers showed little increased adaptation for their working hand, since they were already functioning with visual adaptation and at a level approaching fully adapted (as discussed below). Only the Hi feedback Ss' non-working hand had an opportunity for increased adaptation, since performance was somewhat lower with this hand. Lo feedback Ss were not expected to exhibit significant change in adaptation with either hand, based on the nature of their tasks.

Similarly, based on the level of adaptation of the novices after the first 24 minutes, and the fact that they appeared to be using proprioceptive adaptation, it was expected that Hi feedback working and non-working hands would demonstrate considerable improvement over the experimental sessions. Since the non-working hand of the Hi feedback novices exhibited significant improvement after presentation of the experimental tasks, strong evidence for the start of visual adaptation was obtained. In general, all measures exhibited slight increases for the Hi and Lo novice divers, a fact consistent with the introduction of visual adaptation over time.

Experienced divers demonstrated a generally insignificant, but consistent loss in adaptation after 30 and 36 minutes of U/W exposure; one possible interpretation is the interaction of factors outside the experimental design of the investigation. This slight loss in adaptive effectiveness may have been due to increased chill, simple fatigue or boredom. A similar decrease in apparent distance estimations had been noted in an earlier study for divers observing in a non-work situation (Ono and O'Reilly, 1969). Since the experienced divers appear to have approached a ceiling level of adaptation (approaching fully adapted), they would be more susceptible to the demonstration of competing outside influences. The working and non-working hands of the novices, and the Hi feedback experienced divers' non-working hands, may have been actively improving with continued practice, with this adaptive effect partially cancelled through the hypothesized effects of cold and fatigue. Only further investigation, with the experimental tasks administered earlier in the design, can determine this unequivocally.

One interesting and unexpected result was the failure of targets at different distances from the subject to enhance the absolute magnitude of the after-effect. This result was inconsistent with the optical principles underlying the distortion effect, which should influence the apparent distance proportionally. For the 7 and 14 inch target placements used, absolute adaptation for the 14 inch placement should have been twice that observed for the 7 inch placement.

The greatest amount of absolute adaptation for the 7" stimulus distance occurred for the experienced divers' apparent distance estimations made with the working hand at the end of 24 minutes of practice underwater. The theoretical optimum adaptation (that which would reflect complete elimination of error underwater), would be approximately equal to the ratio of refractive indices (1.33 : 1.00) or an increase of 33 percent. From a pretest average of 6.26 inches the experienced divers averaged 8.14 inches in apparent distance measurements for the testing session ending 24 minutes of practice in the visually distorted environment. This amounted to an increase of 1.88 inches, or 30 percent of the initial setting.

Corresponding maximum adaptation for the 14 inch placement measures also occurred at the end of 24 minutes of U/W psychomotor performance. Here the average apparent distance was 15.70 inches, compared with a pretest average of 13.77--an increase of 1.93 inches or 14 percent of the initial value (approximately half the percentage obtained at the closer distance). Thus, rather than a straight proportional increase in adaptation throughout the range of stimulus distances, as

observed in the U/W SLIDE performance, a relatively constant amount of absolute adaptation was noted for target placements in air.

Since the existence of an after-effect response is indicative of efferent responding with a new coordinating system, competition with a similar existing system may underlie the lack of proportionate adaptation. By occluding the hand from view, the subject received no feedback of his performance (other than through proprioceptive cues) and could be expected to function above water with the same system that had recently been established underwater. The fact that a limit was apparently placed on the absolute amount of over-reach, indicates competition between the newly acquired afferent-efferent coordinating system and that existing for the normal air environment. Since the after-effect testing occurred in the familiar above water environment, with its attending situational cues, competition between the coordinating systems is not too surprising.

Speculating as to the basis for this competition, it can be argued that the relatively less accurate proprioceptive sense allows a margin of flexibility in position sensing before an obvious error is detected. Adaptation could be limited to this "threshold" value, allowing for a certain amount of after-effect over-reaching (or error, in the frame of reference of air responding) before some higher order integrating center overrides the 'errant' positioning response dictated by the newly learned coordinating system.

Although highly speculative, this higher order interaction hypothesis explains fairly well the obtained results. More measurements

at varying distances and in other conflicting environments, are needed before such a general principle can be established.

Results on the underwater performance task (SLIDE apparatus) were generally consistent with the stated hypotheses. There was a significant increase in adaptation over time for both experienced and novice divers. The novices demonstrated a greater rate of adaptation to U/W distance estimation, starting significantly below the experienced divers at the greater stimulus distances, and reaching approximately the same level of performance after 36 minutes underwater.

One unexpected result was the failure of experienced divers to adapt to the level of accuracy registered in the above-water pretest. From anecdotal observations, plus results published by Kinney, et al. (1968a), and postulated effects of conditional adaptation and conscious correction, it was anticipated that fully adapted performance would be obtained from the experienced divers. The results obtained here with a much larger number of subjects cast doubt upon the report by Kinney and co-workers that "(for experienced divers) adaptation is rapid and complete. After 15 to 30 minutes of active manipulation of objects and participation in activities in the distorted situation, individuals can perform perfectly adequately in the new situation" (pg. 8).

Although there was a difference of tasks in the two studies, those provided in the present investigation were specifically developed to increase adaptation, while Kinney et al.'s divers were instructed to be as active as possible, diving for objects, arranging them in patterns, solving crossword puzzles, and playing checkers--all movements capable of complete visual guiding. The testing measures in the two

experiments were roughly equivalent; estimates were taken of target distance in a medial plane, with visual feedback from the reaching hand unavailable to the diver. Target distances were in the same range (4, 8, 10, 10 to Kinney, et al.; 6, 12, 18 for the present study). It was noted in the responses to the SLIDE apparatus that the closest distance provided the least initial error both in actual magnitude and in percent change from air pretests. Perhaps Kinney et al.'s complete adaptation was due to selection of extremely close target distances, providing smaller magnitudes of expected error.

Of the three setting distances used in the present investigation, the six inch distance showed less initial loss in matching accuracy than did either of the greater distances. Relatively accurate reproduction of target settings may be attributable in part to the construction of the testing device; travel cues may have been relatively important since the starting position for each trial was only four inches from the six inch position, and estimates of travel could have been formed. More important, the increased accuracy of the six inch settings would also be due to the greater proportionate adaptation occurring at the closer distances, as noted in the after-effect data mentioned above. Only in the six inch measurements did the subject groups reach the level of their air pretest--actually they surpassed this level, although the mean differences were not significant.

As was noted earlier, there was a consistent increase in absolute error in matching responses as the target distance from the subject increased. This increasing absolute error is in keeping with expectancies based on the underlying optical principles. While a theoretical

error of 25 percent (ratio of 1.00 : 1.33) could be expected, a somewhat reduced actual error was anticipated, attributable to learning of proprioceptive and travel cues at the first (air) administration, plus some conscious correction by the subject. In actuality, the novice divers demonstrated U/W pretest errors of 10 percent, 17 percent and 16 percent from their air pretest settings on the 6, 12 and 18 inch settings respectively. The experienced divers showed errors of 7 percent, 10 percent and 10 percent for the 6, 12 and 18 inch target settings, exhibiting much less initial error than the novice divers when in the visually distorted environment (possibly reflecting a tendency for conditional adaptation, or conscious correction, or a combination of both). Basically, distance estimation performance was in keeping with the underlying optical principles for underwater distortions experienced on the SLIDE apparatus, while inconsistent for after-effect measures taken in an air environment, strengthening the implication of higher order interaction of competing coordinating systems in the situation where there existed the opportunity for both.

While the results of the SLIDE testing were not intended to uncover underlying sensorimotor restructuring occurring during adaptation, the after-effect testing were designed to delineate just such coordinating system changes. In general the results of the after-effect testing have been interpreted as affirmation of the hypothesis that experienced divers exhibit visual adaptation and novice divers exhibit visual adaptation after working on underwater psychomotor tasks.

The underlying bases for this adaptive restructuring are not known. Enough components were available in the experimental design to satisfy

the conditions of a number of competing perceptual theories. Whether the obtained adaptive responses resulted from the establishment of a new reafferent feedback loop initiated by the individual's self-induced movement and conflicting visual input (as hypothesized by Held), or from learned readiness to respond initiated by retinal stimulation (Festinger), is difficult to determine. Actually the similarity of these theoretical positions is great, with Festinger's efferent readiness theory subsuming Held's work, provided an opportunity for learning the new afferent-efferent associations is available. In the interest of parsimony, adaptation to distance distortion obtained in this investigation will be considered in Festinger's theoretical framework. The results can thus be considered as learning derived from changes in sets of efferent instructions activated by afferent visual input.

An implication from this theoretical approach is that maximum adaptation is provided by tasks inducing learning of new afferent-efferent associations. Tasks such as UDLA, restricting visual guiding while providing ballistic movement and knowledge of results, rely on efference issued relevant to the target distance involved. Within the distorted visual field normal above-water afferent-efferent associations are inadequate for successful performance on the UDLA, therefore it is assumed that new afferent-efferent associations are being learned during the U/W practice sessions. While no definite statement can be drawn from the data contrasting task effectiveness, partially because of small sample size, tends toward increased adaptation were apparent when performance on UDLA was compared with that on MRMT.

While performance of the experienced divers is amenable to interpretation as visual adaptive responding, evaluation of alternate explanations for the acquisition on non-working hand adaptation should be considered. The first such alternate interpretation accounting for proprioceptive adaptation in a non-working hand is intermanual transfer. As mentioned earlier numerous investigators have reported no indication of adaptation transferring from a working to a non-working hand under conditions designed for proprioceptive adaptation--the whole basis for this investigation was to show that non-working hand adaptation can only be exhibited in an unusual circumstance, one where visual adaptation is the only consistent explanation. As evidence for this contention, the inexperienced divers exhibited no adaptive transfer in this design, although subjected to the same visual distortion and psychomotor tasks as the experienced divers.

A more subtle suggestion might be posed regarding the possibility of experienced divers exhibiting reestablishment of conditional proprioceptive adaptation independently acquired by each hand during previous visual-motor performances underwater. The best refutation is to note that conditional adaptation to the U/W distance distortion was not found in sufficient magnitude to warrant its consideration as a major explanation for obtained adaptation. Experienced divers evidenced significant loss in accuracy of distance estimations on the SLIDE apparatus while underwater, with gradual adaptation over time. After-effect testing also showed significantly increased adaptation with continued practice underwater.

Furthermore, a previous pilot study found no adaptive shift in hand responses for experienced divers when viewing, but not working, underwater. In this situation there was no evidence of adaptation occurring over time for a hand not working in the distorted environment (actually, negative apparent distance measures were recorded). If conditional adaptation was the important process, just being underwater should inspire some adaptive responses. Since both the pilot and the present study found adaptation appearing only after working in the distorted environment, and since it was accepted that proprioceptive adaptation does not transfer, the non-working hand of the experienced divers could not have exhibited adaptation based on prior proprioceptive relearning. Only implementation of recoding in a system operating for both working and non-working hands would satisfy the obtained results--establishment of learned movements based on new efferent sets activated by afferent visual input is the only consistent explanation.

To further pursue the interpretations presented here, additional measures should be secured that provide unequivocal support for visual restructuring. Several supplementary dependent measures had been considered for this investigation, but were omitted for various reasons, including greatly increased testing time above water. With the basic phenomenon established, investigation can shift to more accurate determination of the parameters involved in proprioceptive and visual adaptation.

Exactly how the various sensory systems recode information in establishing new afferent-efferent correlations cannot be determined

from this investigation. Hay and Pick (1966) and McLaughlin and Bower (1965) postulated a change in felt-position of the eye with the onset of prismatically induced visual adaptation, a contention strengthened by photographic evidence that postural changes in the eye occur with prism adaptation (Kalil and Freedman, 1966). (It is interesting to observe that investigators continue to postulate change in eye position as a cue in establishing new efference, although Brindley and Merton (1954) noted an absence of proprioceptive position sensing in the eyes.)

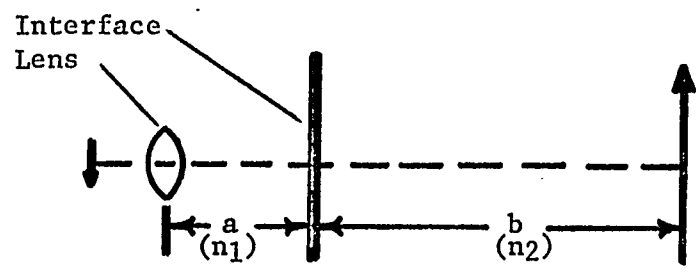
The availability of muscular cues from increased convergence and accommodation due to displacement of the virtual image underwater might serve a function analagous to "felt-position" of the eye in adding visual adaptation to distance distortion. However, there is also some controversy regarding the actual functioning of these muscular changes. Several authors (Gogel, 1961; Richards and Miller, 1969) have shown that not all individuals use convergence as distance cues. Others (Ames and Ittleson, 1950) have speculated that convergence and accommodation may come about due to apparent distance, not act as a determinant of it.

Nevertheless, these oculomotor processes are generally considered as effective cues for close distances. Their limitation to closer distances might explain why this investigation obtained results in agreement with those anticipated from consideration of the optical principles involved, i.e. increased after-effect above water, and underestimation of real distance underwater, while most other studies have shown overestimations from real distance at greater target placements.

In addition to loss of accommodation and convergence as distance cues, introduction of other variables such as illumination, turbidity, contrasts, and object surroundings must be considered when target distances differ. For close distances additional factors must be recognized which have not been discussed previously, particularly thickness of the glass interface, distance from target to interface, and distance from subject to interface.

The changing relationship between apparent distance and real distance with change in target to interface distance is approximated in Figure 10, where apparent distance (AD) is defined as a percent of the total distance. AD varies with location of the interface from the limiting case equaling the total distance (interface set at minimum distance from target), to where it assumes the 75 percent of real distance relationship commonly accepted by investigators. For the standard facemask with an average eye to interface distance of approximately 1.5 inches (range of subjects tested on Healthways mask: 1.4 to 1.95 inches), there should be negligible departure from 25 percent distance reduction over 36 inches away. For the present experiment, the virtual image should have been approximately 20 percent to 22.5 percent closer to the subject than the real distance (for the 6 and 18 inch distances respectively), rather than the hypothetical 25 percent commonly stated.

In terms of after-effect necessary to adjust for this underestimation, adjusting for the effect of interface placement in the present study changes the theoretical magnification of 33 percent to values between 25 percent and 29 percent, in close agreement with the



$$AD @ (a + (b/1.33)) + \Delta a (1 - (1/1.33))$$

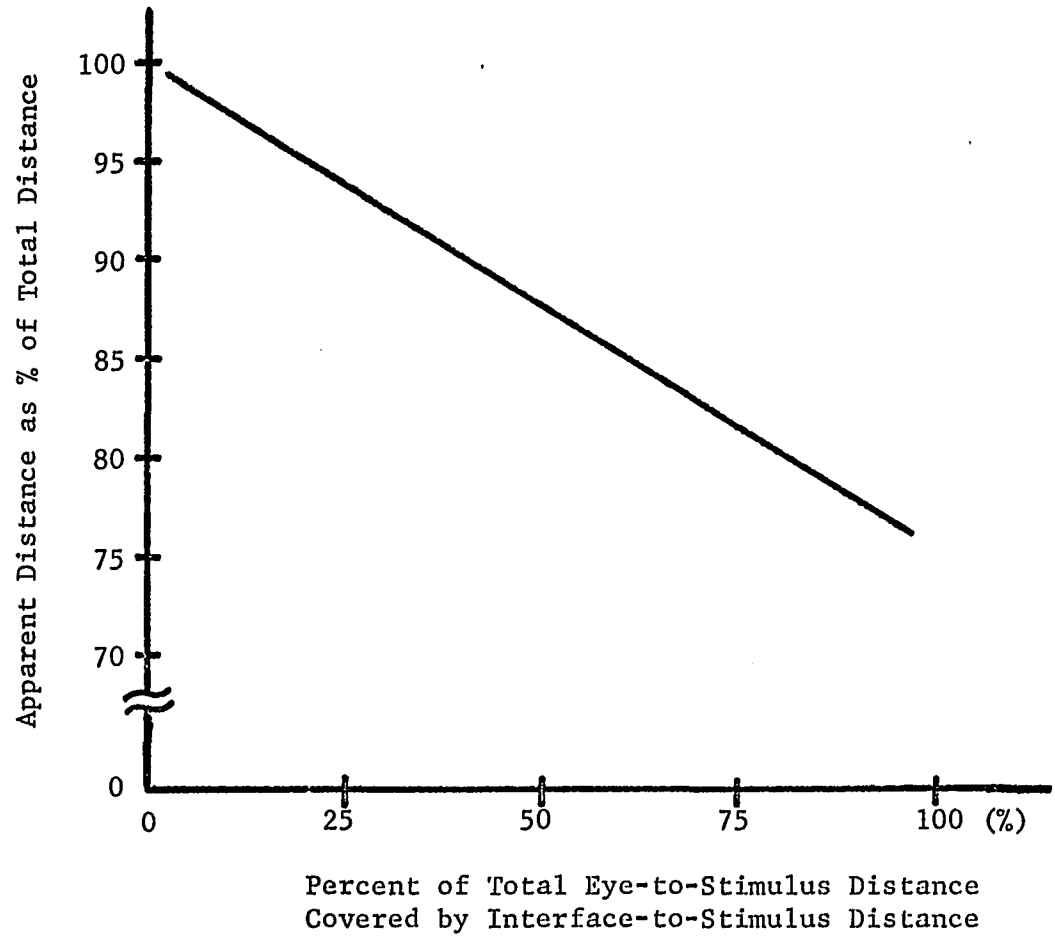


FIGURE 10  
 Relationship Between Apparent Distance  
 and Position of Interface

maximum over-reach noted by the experienced divers of 30 percent increase from pretest. (Kinney and Luria, 1969, mention a magnification factor of 27 percent for "distances common to facemasks" when dealing with size change, reflecting recognition of the importance of eye-interface-object distances.)

This reduction in the discrepancy between apparent and real distances affects closer distance placements; with displacement from the real distance only 17.5 percent reduced for the 4 inch target distance used by Kinney, et al. (1968a). Greater adaptation should be found for closer targets due to this effect, plus the related effect that, in terms of absolute distance, the discrepancy between AD and real distance is proportionately less (AD is displaced approximately 3.5 inches closer to the S for a target placed at a real distance of 18 inches, and only 0.7 inches closer for a target at four inches). As postulated earlier, small discrepancies can be more easily assimilated in the newly restructured coordinating system than can larger ones. The problem can be confounded when utilizing porthole viewing, where the subject can often be considerably farther behind the interface than is common with facemask viewing.

Thickness of the glass interface can also be an important variable in contrasting obtained results. Numerous investigators have utilized observation tasks where the subject views through a porthole into a diving tower. Since these windows must be relatively thick to withstand the water pressure, adjustments must be made for the increased visual angle when the obtained results are compared with those utilizing a standard facemask.

Although generally neglected, some detectable change in apparent distance might be occurring even when viewing through a 3mm glass plate such as that in a facemask. Figure 11 summarized the results of pretest measures for three studies performed by this author. In all but one case, there is a slight underestimation of the real distance when the target was viewed in air, with this underestimation fairly linear through the target distances used. It is possible that interposition of the faceplate is the cause of the underestimation; studies are presently being conducted to determine just how much the interface contributes to the underestimation.

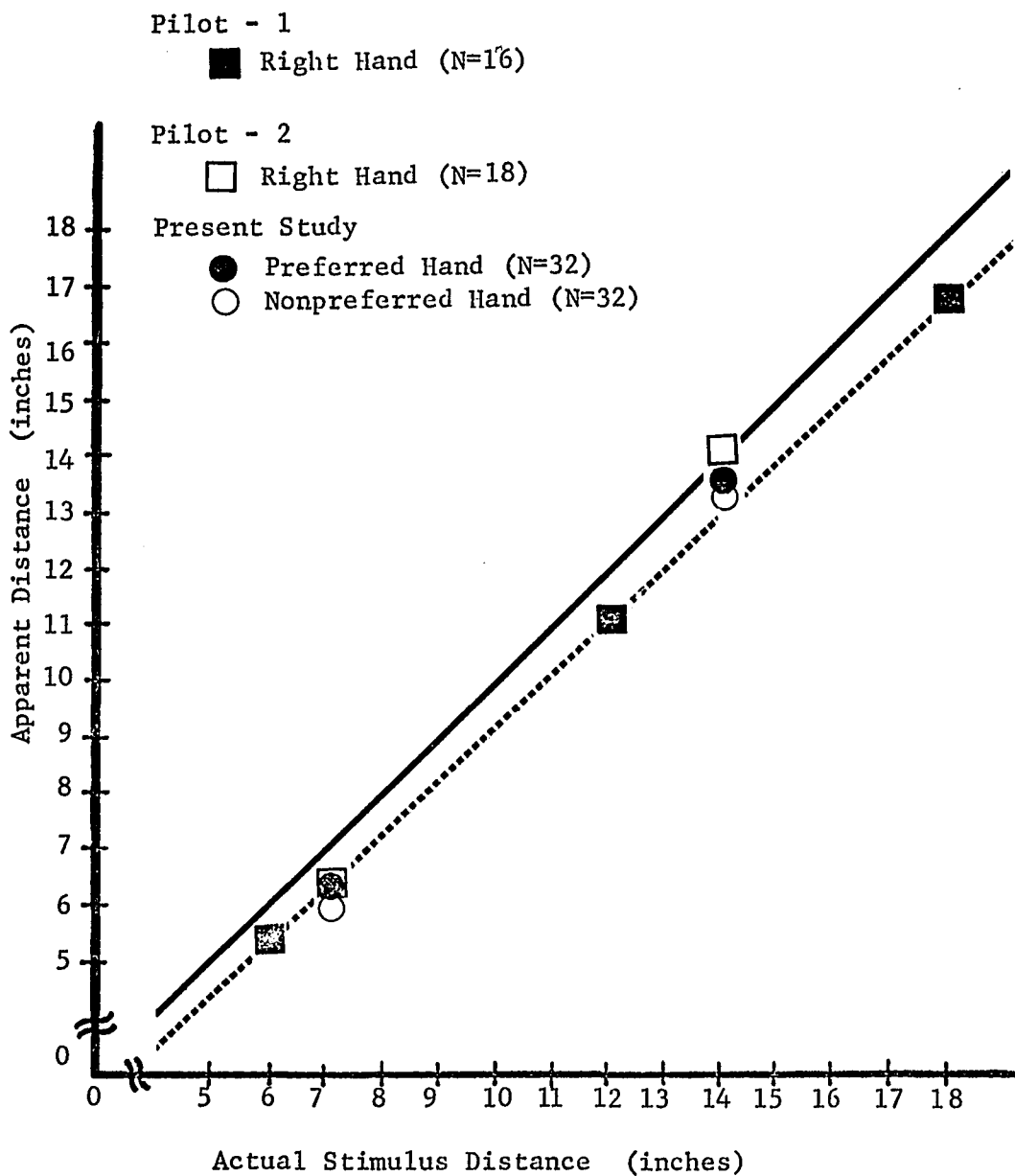


FIGURE 11

Comparison of Apparent and Actual Distances  
 On Above-Water Measurements From 3 Studies

## CHAPTER V

### CONCLUSIONS

The results of the present study supported the hypotheses that novice and experienced subjects utilized different adaptive methods in adjusting to distance distortion through a water-air interface. According to the operational definitions accepted at the inception of the investigation, the experienced divers exhibited visual adaptation, as measured by similar after-effect responses produced by both working and non-working hands. Inexperienced divers showed proprioceptive adaptation to the U/W distortion, as exhibited by a difference in after-effect responding for working and non-working hands.

As hypothesized, experienced divers exhibited greater over-reach (reflecting increased adaptation) over time on the A-ETD than did the novices. Continued adaptation over time was found for the experienced divers, while the novices demonstrated a lower, but consistent, level of adaptation from the first 12 minute testing. As had been found in prism-distortion research, proprioceptive adaptation occurred rapidly, within the first 12 minutes of U/W performance for the novices; the experienced divers, utilizing visual adaptation, adapted to the same level initially, but perceived distance increased significantly after the second (24 minute) testing.

On the SLIDE task, measuring accuracy of distance estimation while in the water, experienced divers made smaller errors in distance matching than the novices at each target placement, as was expected.

Accuracy of distance matching increased for both groups over time, with the novices reaching approximately the same level of accuracy as the experienced divers after 36 minutes of exposure to the distorted visual input. This result was contrary to the hypothesis that novices would adapt less than the experts, and was in disagreement with results from a comparable study.

Introduction of experimental tasks differing in amount of available feedback concerning the distortion generally produced the hypothesized results, although there was some indication of confounding with fatigue, cold, and motivational factors which tended to depress improvement in adaptive responding. Both novice and expert high feedback subjects appeared to be exhibiting increased visual adaptation; even the novice low feedback group showed some improved responding with their non-working hand during the last two A-ETD testings, reflecting a possible shift to visual adaptation. Further investigation into the effects of the high and low feedback tasks is necessary, with the tasks presented earlier, and for a longer period.

Although the adaptation period tasks (the UDLA and MRMT) did not significantly differ on their ability to induce adaptation in the divers' responding, there was a consistent difference between the tasks in the hypothesized direction - the task designed to provide the greatest opportunity for ballistic movement (the UDLA) tended to induce the greatest amount of after-effect on the A-ETD.

The effectiveness of distance estimation responding was found to vary with the distance of the target from the subject. In the air testings, measures of after-effect decreased proportionately with

increased target distance, with a relatively constant absolute amount of over-reach across distances. In the U/W testings on the SLIDE, subjects demonstrated increased absolute error with increased distance of target placement, with a corresponding equal proportional error across distances. The after-effect results failed to support the hypothesis that the absolute magnitude of adaptative responding would increase with target distance from the subject, while the SLIDE results confirmed this expectation. Suggestions designed to explain this discrepancy have been presented.

In summary, adaptation to distance-displaced visual images does occur. Indications of different methods for producing this adaptation were found between subjects with extended experience in the water environment and those relatively inexperienced in underwater performance. Results of the present study also suggest that appropriate selection of tasks can aid in inducing these various modes of adapting.

The underlying physiological structures involved in re-establishing eye-hand coordination for effective reaching performance in a 'distorted' environment are not known, nor was this investigation designed to determine neurological structure and function. The study did demonstrate further instances of plasticity in human sensing capabilities.

Proprioceptive sensing was initially altered for the novices, as evidenced by changing performance of the working hand during reaching estimations. The phenomenon of "visual capture," or domination of vision over proprioception, had been demonstrated many time before. This investigation produced evidence that postural cues utilized in

hand extensions during reaching were susceptible to visual dominance; the working hand established a new set of efferent movement when visually altered input were presented.

Evidence for visual restructuring, as postulated for the experienced divers, is more equivocal. Too little is known regarding higher order multi-modal sensory integration in the human to establish the precise manner of eye-hand recording that occurs during adaptation. Before the occurrence of visual adaptation can be definitely established additional experimentation is necessary. Use of tasks involving only visual input, such as visually matching a standard, are suggested to provide converging operations for establishing change in visual perception. Several oculomotor cues capable of assisting in restructuring visual perception of distance were discussed, but they do not, in themselves, constitute sufficient evidence for visual adaptation. Laboratory studies duplicating the design in its essential aspects are also recommended, especially to establish performance histories not confounded with possible earlier proprioceptive learning or conditional adaptation.

Several considerations are presented for applying the results of this investigation to the problem of effective performance of Man in the Sea. Divers can be expected to exhibit errors in estimation of distances, even within arm's reach. Underestimation of actual distance was found for these close distances; other investigations report overestimation for greater distances. Diving experience is related to amount of error, with experienced divers demonstrating less initial error than novices. Adaptation, or decrease in error of estimation

while underwater, occurs over time for both novices and experts, indicating some possible advantage in introducing "warm-up" tasks before critical U/W operations.

After-effects in air were found to be quite high, up to 30 percent over-reach for closer distances, after the diver had been functioning in the water environment for a period of time. Tasks requiring ballistic reach, or resulting in proximal-distal movements without close visual guidance should be avoided immediately after emerging from the water.

In general, results from this study illustrate the advantage of utilizing a natural source of visual distortion, since an available pool of subjects experienced in functioning in the 'distorted' environment exists. Additional utilization of the natural semi-weightlessness and decorrelation conditions unique to this environment is also encouraged to further extend knowledge of sensory functioning in the human.

## REFERENCES

- Ames, A. & Ittleson, W. H. Accommodation, convergence, and their relation to apparent distance. Journal of Psychology, 1950, 30, 43-62.
- Barnard, E. E. P. Visual problems under water. Proc. Royal Soc. of Medicine, 1961, 54, 755-756.
- Bowen, H. M. Diver performance and the effects of cold. Human Factors, 1968, 10, 445-464.
- Bowen, H. M., Andersen, B., & Promisel, D. Studies of divers' performance during the SEALAB II project. Human Factors, 1966, 6, 183-199.
- Brindly, G. S., & Merton, P. A. Absence of position sense in the eye. Journal of Physiology, 1954, 153, 121-130.
- Burnham, C. A. Effect of efference to the arm on visual adaptation to prismatically induced curvature. Proceedings, 74th Annual Convention, APA, 1966, 11-12.
- Canon, L. K. Adaptation to simultaneous displacements of the visual and auditory fields. Proceedings, 74th Annual Convention, APA, 1966, 13-14.
- Christianson, R. A. A study of visual acuity underwater using an automatic landolt ring presentation technique. Research Report X8-128/020, February, 1968, Ocean Systems Operations, North American Rockwell Corporation, Long Beach, California.
- Cohen, H. B. Transfer and dissipation of after-effects due to displacement of the visual field. American Psychologist, 1963, 18, 411. (Abstract)

- Davidon, R. S. Intermodal effect upon haptic judgments of distance. Proceedings, 75th Annual Convention, APA, 1967, 23-24.
- Educational Test Bureau. Minnesota Rate of Manipulation Test - Examiner's Manual. Minneapolis: Educational Publishers, 1946.
- Efstathiou, A., Bauer, J., Greene, M., & Held, R. Altered reaching following adaptation to optical displacement of the hand. Journal of Experimental Psychology, 1967, 73, 113-120.
- Epstein, W. Varieties of Perceptual Learning. New York: McGraw-Hill, 1967.
- Faust, K. J., & Beckman, E. L. Evaluation of a swimmer's contact air-water lens system. Military Medicine, 1966, 131, 779-788.
- Festinger, L., Burnham, C. A., Ono, H., & Bamber, D. Efference and the conscious experience of perception. Journal of Experimental Psychology, 1967, 74, 1-36.
- Fox, W. F. Human performance in the cold. Human Factors, 1967, 9, 203-220.
- Gogel, W. C. Convergence as a cue to absolute distance. The Journal of Psychology, 1961, 52, 287-301.
- Gogel, W. C. The visual perception of size and distance. Vision Research, 1963, 3, 101-120.
- Gogel, W. C., & Newton, R. E. Perception of off sized objects. Perception and Psychophysics, 1969, 5, 7-9.
- Gregory, R. L. Eye and Brain - The Psychology of Seeing, New York, McGraw-Hill, 1966.
- Hamilton, C. R. Intermanual transfer of adaptation to prisms, American Journal of Psychology, 1964, 77, 457-462.

- Hamilton, C. R., & Bossom, J. Decay of prism after-effects. Journal of Experimental Psychology, 1964, 67, 148-150.
- Harrington, T. L. Adaptation of humans to colored split-field glasses. Psychonomic Science, 1965, 3, 71-72.
- Harris, C. S. Adaptation to displaced vision: visual, motor, or proprioceptive change. Science, 1963, 140, 812-813.
- Harris, C. S. Perceptual adaptation to inverted, reversed, and displaced vision. Psychological Review, 1965, 72, 419-444.
- Hay, J. C., & Pick, H. L. Visual and proprioceptive adaptation to optical displacement of the visual stimulus. Journal of Experimental Psychology, 1966, 71, 150-158.
- Hay, J. C., & Pick, H. L. Gaze-contingent prism adaptation: optical and motor factors. Journal of Experimental Psychology, 1966, 72, 640-648.
- Hay, J. C., Pick, H. L., & Ikeda, K. Visual capture produced by prism spectacles. Psychonomic Science, 1965, 2, 215-216.
- Held, R. Motor-sensory feedback and the geometry of visual space. Science, 1963, 141, 722-723.
- Held, R. Plasticity in sensory-motor systems. Scientific American, 1965, 84-94.
- Held, R., & Freedman, S. J. Plasticity in human sensorimotor control. Science, 1963, 142, 455-461.
- Held, R., & Gottlieb, N. Technique for studying adaptation to disarranged hand-eye coordination. Perceptual and Motor Skills, 1958, 8, 83-86.

- Held, R., & Hein, A. Adaptation to disarranged hand-eye coordination contingent upon re-afferent stimulation. Perceptual and Motor Skills, 1958, 8, 87-90.
- Held, R., & Hein, A. Movement produced stimulation in the development of visually guided behavior. Journal of Comparative Physiological Psychology, 1963, 56, 872-876.
- Held, R., & Rekosh, J. Motor sensory feedback and the geometry of visual space. Science, 1963, 141, 722-723.
- Held, R., & Schlank, M. Adaptation to disarranged eye-hand coordination in the distance dimension. American Journal of Psychology, 1959, 72, 603-605.
- Helmholtz, H. von. Physiological Optics. (Translated by J. P. C. Southall) Vol. III. Optical Society of America, 1925.
- Hutton, R. S. Kinesthetic after-effect, a measure of kinesthetic awareness, Perceptual and Motor Skills, 1966, 23, 1165-1166.
- Hochberg, J. On the importance of movement produced stimulation in prism-induced after-effects. Perceptual and Motor Skills, 1963, 16, 544.
- Kalil, R. E., & Freedman, S. J. Persistence of ocular rotation following compensation for displaced vision. Perceptual and Motor Skills, 1966, 22, 135-139.
- Kent, P. R. Vision underwater. American Journal of Optometry and Archives of American Academy of Optometry, 1966, 43, 553-565.
- Kiessling, R. J., & Maag, C. H. Performance impairment as a function of nitrogen narcosis. Journal of Applied Psychology, 1962, 46, 91-95.

- Kinney, J. S., & Cooper, J. C. Adaptation to a homochromatic visual world. SMRL Report No. 499, Naval Submarine Medical Center, Groton, Conn. July 28, 1967.
- Kinney, J. S., & Luria, S. M. Conflicting visual and tactual stimulation. Paper read at Annual Meeting of the Eastern Psychological Association, Philadelphia, April, 1969.
- Kinney, J. S., Luria, S. M., & Weitzman, D. O. Visibility of colors underwater, Journal of the Optical Society of America, 1967, 57, 802-809.
- Kinney, J. S., Luria, S. M., & Weitzman, D. O. Responses to the underwater distortions of visual stimuli. SMRL Report No. 541, U. S. Naval Submarine Medical Center, Groton, Conn., July 16, 1968. (a)
- Kinney, J. S., Luria, S. M., & Weitzman, D. O. The underwater visibility of colors with artificial illumination. SMRL Report No. 551, U. S. Naval Submarine Medical Center, Groton, Conn., October 15, 1968. (b)
- Kinney, J. S., Luria, S. M., & Weitzman, D. O. Effect of turbidity on judgments of distance underwater. Perceptual and Motor Skills, 1969, 28, 331-333.
- Kohler, I. Uber und wandlungen der wahrnehmungswelt. SB Ost. Akad. Wiss, 1951, 227, 1-118. (trans. by H. Fiss, 1964, cited in Epstein, 1967).
- Kravitz, J. H., & Wallach, H. Adaptation to displaced vision upon vibrating stimulation. Psychonomic Science, 1966, 6, 465-466.
- Lazar, G. Adaptation to displaced vision as a function of direction of hand movement. Perceptual and Motor Skills, 1966, 22, 521-522.

- Leibowitz, H. W. Visual Perception. New York, Maxmillan, 1965.
- Lindquist, E. F. Design and analysis of experiments in psychology and education. Boston: Houghton Mifflin, 1956.
- Lit, A. Visual acuity. In P. R. Farnsworth, M. R. Rosenzweig, & J. T. Polefka (Eds.), Annual review of psychology, Palo Alto, Calif., 1968.
- Luria, S. M. Stereoscopic acuity underwater. SMRL Report No. 510, U. S. Naval Submarine Medical Center, Groton, Conn., February 28, 1968. (a)
- Luria, S. M. Stereoscopic and resolution acuity with varying field of view, SMRL Report No. 557, U. S. Naval Submarine Medical Center, Groton, Conn., December 6, 1968. (b)
- Luria, S. M., & Kinney, J. S. Judgments of distance under partially reduced cues. SMRL Report No. 542, U. S. Naval Submarine Medical Center, Groton, Conn., July 24, 1968. (a)
- Luria, S. M., & Kinney, J. S. Stereoscopic acuity underwater. The American Journal of Psychology, 1968, 81, 359-366. (b)
- Luria, S. M., & Kinney, J. S., & Weissman, S. Estimates of size and distance underwater. The American Journal of Psychology, 1967, 80, 282-286.
- MacInnis, J. B. The medical and human performance problems of living under the sea. Canadian Medical Association Journal, 1966, 95, 191-200.
- McLaughlin, S. C., & Bower, J. L. Selective intermanual transfer of adaptive effects during adaptation to prism. Psychonomic Science, 1965, 3, 69-70.

- McLaughlin, S.C., & Rifkin, K. I. Change in straight ahead during adaptation to prism. Psychonomic Science, 1965, 2, 107-108.
- Mikaelian, H. Failure to bilateral transfer in modified eye-hand coordination. Paper read at Eastern Psychological Association Meeting, New York, 1963 (cited in Efstathiou, et al., 1967).
- Mikaelian, H., & Held, R. Two types of adaptation to an optically-rotated visual field. The American Journal of Psychology, 1964, 77, 257-263.
- Newton, A. S. Underwater vision. Journal of the American Optometry Association, 1967, 38, 69-70.
- Ono, H., & O'Reilly, J. P. Distance distortion underwater and subsequent adaptation, Human Factors, (in press).
- Pick, H. L. Perception in soviet psychology. Psychological Bulletin, 1964, 62, 21-35.
- Pick, H. L., & Hay, J. C. Gaze-contingent adaptation to prism spectacles. The American Journal of Psychology, 1966, 79, 443-450.
- Posner, M. I. Characteristics of visual and kinesthetic memory codes. Journal of Experimental Psychology, 1967, 75, 103-107.
- Richards, W., & Miller, J. F. Convergence as a cue to depth. Perception and Psychophysics, (in press).
- Rierdan, J. E., & Wapner, S. Experimental study of adaptation to visual rearrangement deriving from an organismic-developmental approach to cognition. Proceedings, 74th Annual Convention, APA, 1966, 15-16.

- Rierdan, J. E., & Wapner, S. Experimental study of adaptation to visual rearrangement deriving from an organismic-developmental approach to cognition. Perceptual and Motor Skills, 1966, 23, 903-916.
- Rock, I. The nature of perceptual adaptation. New York: Basic Books, 1966.
- Rock, I., & Harris, C. S. Vision and touch. Scientific American, 1967, May, 96-104.
- Ross, H. E. The size-constancy of underwater swimmers. Quarterly Journal of Experimental Psychology, 1965, 17, 329-337. (a)
- Ross, H. E. Size and distance judgments under water and on land. Symposium Underwater Association for Malta, 1965, 19-22. (b)
- Ross, H. E. Stereoscopic acuity under water. Symposium Underwater Association for Malta, 1966-1967, 61-64. (a)
- Ross, H. E. Water, fog, and the size-distance invariance hypothesis. British Journal of Psychology, 1967, 58, 301-313. (b)
- Ross, H. E. Judging distance underwater. Triton, 1968, 13, 64-66. (a)
- Ross, H. E. Personality of student divers. Symposium Underwater Association for Malta, 1968, 59-62. (b)
- Ross, H. E., & Lennie, P. Visual stability during bodily movement underwater. Symposium Underwater Association for Malta, 1968, 55-57.
- Shaffer, O., & Wallach, H. Adaptation to displaced vision measured with three tests. Psychonomic Science, 1966, 6, 143-144.
- Stratton, G. M. Vision without inversion of the retinal image. Psychological Review, 1897, 4, 341-360. (Reprinted in

- Dennis, W. Readings in General Psychology. Englewood Cliffs, N. J.: Prentice-Hall, 1949.)
- von Holst, E. Relations between the central nervous system and the peripheral organs. Animal Behavior, 1954, 2, 84-94. (reprinted in Leibowitz, 1965).
- Wallach, H., & Frey, K. J. Adaptation in the constancy of visual direction measured by a one-trial method. Perception & Psychophysics, 1969, 5, 249-252.
- Wallach, H., Kravitz, J. H., & Lindauer, J. A passive condition for rapid adaptation to displaced visual direction. The American Journal of Psychology, 1963, 76, 568-578.
- Weltman, G., Christiansen, R. A., & Egstrom, G. H. Visual fields of the scuba diver. Human Factors, 1965, 5, 423-430.
- Weltman, G., & Egstrom, G. H. Perceptual narrowing in novice divers. Human Factors, 1966, 6, 499-506.
- Winer, B. J. Statistical principles in experimental design. New York: McGraw-Hill, 1962.

## SUPPLEMENTARY READINGS

- Dugan, J., Cowen, R. C., Barada, B., Marden, L., & Crum, R. M.  
World Beneath the Sea. Washington, D. C.: National Geographic  
Society, 1967.
- Kohler, I. Experiments with goggles. Scientific American, 1962,  
206, 62-84.
- Radloff, R., & Helmreich, R. Groups Under Stress: Psychological  
Research in SEALAB II. New York: Appleton-Century-Crofts, 1968.
- Rock, I. When the world is tilt: Distortion - how we adapt.  
Psychology Today, July, 1968.