Loss of position constancy underwater*

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It was predicted that, due to the optical distortion produced by wearing a face mask, the constancy of visual position would not be maintained underwater, i.e., stationary objects should appear to move when the head is moved. Ss rotated their heads about a vertical axis and made magnitude estimates of object movement in both air and water. Twice as much movement occurred in water as in air. Two underwater activities, head rotation while observing vertical stripes and practice in hand-eye coordination, produced a small reduction in the loss of position constancy.

When a stationary observer views a physically moving object, a moving pattern of retinal stimulation is produced which gives rise to the perception of a moving object. However, an identical retinal movement can occur when the object is stationary but the observer moves. The term constancy of visual position (or visual direction) refers to the fact that stationary objects do not appear to move when the observer moves. A mechanism apparently exists whereby the extent of retinal movement is compared with the amount of eye, head, or body movement. When these two sources of stimulus input "match," the result is the perception of a stationary visual world (Teuber, 1960). Wallach & Kravitz (1965a, b, 1968) have studied this process in considerable detail. By means of a variable-ratio mechanical linkage between head movement and stimulus movement, they verified that a single target in darkness remains stationary when the head movement and the retinal image movement properly correspond. When the amount of image movement was artificially altered, predictable target movement was perceived. Furthermore, prolonged experience with the distorted relationship between head and image movement, using lenses, resulted in an adaptation to the distortion, i.e., less movement was produced by the distorted arrangement, and opposite movements (an aftereffect) occurred when the head-image relationship was restored to normal.

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In previous research, distortion of position constancy has been artificially produced in the laboratory. There is a natural situation, however, which theoretically should produce a similar distortion. When a diver wears a face mask underwater, light refraction at the water-air interface magnifies the retinal image of an object by a factor of about 1.27, a condition sufficient for upsetting the normal head-image relationship. Therefore, it may be predicted that the constancy of visual position will not be maintained underwater, i.e., objects will appear to move when the head is moved. A further prediction is that experience in the underwater environment will produce a reduction in the amount of apparent object movement. These two predictions were tested in the present experiment.

SUBJECTS

Eighty Navy enlisted men served as Ss. A majority of the Ss had little or no previous diving experience, and none had any prior experience with the experimental situation.

APPARATUS

The difficulties inherent in working underwater made it unfeasible to use a complicated mechanical or electronic system for precisely measuring apparent object movement. The simpler method of direct magnitude estimation was used instead. The experiment was carried out in an outdoor, above-ground swimming pool, which was 6.10 m in diam and 111.8 cm deep. A white background, 1.52 m wide, was mounted against the wall of the pool. It extended above the surface from the bottom of the pool to a height of 2.21 m. A horizontal rod was mounted just below the surface, parallel to the background and 91.4 cm away. This rod served as a marker for the S's head position. A vertical test rod, 1.27 cm in diam and painted fluorescent red-orange, was placed 45.7 cm from the S and centered against the background. The S wore a face mask, snorkel, and weight belt.

PROCEDURE

The Ss were assigned to one of four groups, 20 Ss in each. The initial procedure was the same for all groups. The S stood facing the background, and, with the test rod temporarily removed, a similar vertical rod was held in front of the S. The S was instructed to rotate his head rhythmically from side to side about a vertical axis and to report whether he observed any movement of the rod. Almost all Ss perceived a slight movement. The S was informed that the amount of movement he had just perceived had an arbitrary reference magnitude of "10," and that his task was to make some additional judgments of degree of movement in relation to this reference movement, i.e., relative to 10. To further explain this scaling procedure, it was stated that for movement greater than the reference movement, a number larger than 10 should be chosen, and for movement less than the reference movement, a number less than 10 should be chosen. The S was then asked to observe the reference movement a second time. When the S was satisfied that he knew what the reference magnitude looked like, the temporary vertical rod was removed, the test rod was replaced, and the S lowered himself into the water. With his eyes first just above the water and then just below the water, the S rotated his head and decided on a number for the amount of movement observed. The air and water numbers were both reported when the S returned to the surface.

The procedure which followed differentiated the four experimental groups. Members of the head-movement-in-water (HMW) group sat underwater, 91.4 cm from a sheet of clear Plexiglas which was 101.6 cm high and 78.7 cm wide and which contained 2.54-cm-wide vertical red stripes. The Ss rotated their heads for 15 min while looking at the stripes. Wallach & Kravitz (1965b) found that a similar head-movement procedure produced significant adaptation. After this adaptation period, the Ss returned, underwater, to the test rod and made two final motion judgments, first in water and then in air. Members of the head-movement-in-air (HMA) group followed the same procedure, but looked at the stripes in air rather than underwater. Members of the checkers-in-water (CW) group (two at a time) played a game of checkers underwater during the 15-min adapting period. Playing checkers underwater is known to produce adaptation to distortion in hand-eye coordination (McKay, Kinney, & Luria, 1971). This activity provides practice in hand-eye coordination to

Table 1
Median Ratios Between Magnitude Estimates

	$Water_2/Water_1$		Air_2/Air_1	
Group	Median	SIQR	Median	SIQR
HMW	0.94	0.17	1.33	0.53
CW	0.83	0.16	1.14	0.55
HMA	1.05	0.19	1.00	0.04
NA	1.00	0.12	1.00	0.15

the displaced images, while at the same time insuring adequate S motivation and attention. Members of the final no-adaptation (NA) group relaxed outside the pool during the adaptation period.

RESULTS

Initial Air-Water Difference

As a measure of the relative difference between their initial air (Air_1) and their initial water ($Water_1$) estimates, the ratio $Water_1/Air_1$ was computed for each S. Since this ratio was greater than 1.0 for all but one S, constancy of visual position was not maintained underwater. The median ratio was 2.0 for the 80 Ss, with a semi-interquartile range (SIQR) of 0.75. The Ss reported seeing only a slight movement of the rod in air, presumably due to the presence of peripheral stimuli and perhaps due to imperfect eye tracking. But under water, the rod distinctly jumped from side to side, coincident with the head movements. Of course, the crudeness of the response measure precludes a precise statement as to the amount of distortion in terms of a true ratio-scale measure.

Adaptation

The ratio of the final to the initial water estimate ($Water_2/Water_1$) and the ratio of the final to the initial air estimate (Air_2/Air_1) were computed for each S. The median ratios and SIQRs for the four groups are listed in Table 1. A water ratio less than 1.0 represents compensation for the distortion, and an air ratio greater than 1.0 represents an aftereffect. The results indicate that the two groups who remained under water during the adaptation period (HMW and CW) did, in fact, show a slight adaptation to the distortion of position constancy. The two air-control groups showed no adaptive changes. The statistical significance levels for between-group ratio differences (Mann-Whitney test, one-tailed) are given in Table 2. Since the significance levels in some cases are quite marginal, conclusions regarding the occurrence of adaptation must remain tentative. In view of the considerable individual differences observed in this experiment, a more precise method for measuring target movement would be desirable for assessing adaptive changes.

Table 2
Statistical Significance Levels of Ratio Differences Between Groups (Mann-Whitney Test)

Group	HMA	CW	NA
		$Water_2/Water_1$	
HMW	.05	n.s.	n.s.
HMA		.01	.01
CW			.10
		Air_2/Air_1	
HMW	.025	n.s.	.025
HMA		.10	n.s.
CW			.10

Effect of Previous Diving Experience

Since the adaptation procedure used in this experiment apparently produced a slight reduction in target movement, it might be expected that Ss having considerable previous diving experience would show less target movement underwater than inexperienced Ss. By means of a questionnaire filled out by all Ss prior to the experiment, information was obtained concerning their degree of previous experience. There was no relationship between previous experience and initial distortion ($Water_1/Air_1$). Furthermore, for the two water groups (HMW and CW), there was no relationship between experience and either the amount of compensation in water or the amount of aftereffect in air. The unimportance of previous experience is surprising, since experienced Ss show less underwater distortion of hand-eye coordination than do inexperienced Ss (Kinney, Luria, Weitzman, & Markowitz, 1970).

DISCUSSION

The results verify the prediction that the constancy of visual position is not maintained underwater. This outcome results directly from the optical distortion produced by wearing an air-filled face mask. For an object at a particular physical distance, the amount of retinal-image movement produced by a given head movement is greater underwater than in air. As a result, the visual and proprioceptive inputs underwater do not match, and the object appears to move.

Since adaptation to experimentally produced loss of constancy occurs in air, it is not surprising that the second prediction of an adaptation to apparent object movement underwater was tentatively verified. Although a precise statement as to the amount of adaptation which occurred cannot be made, it is clear that the adaptation was small in comparison with the amount of initial distortion. The fact that previous diving experience was not related to the amount of initial distortion in position constancy may be related to a similar finding in regard to distortion of size and distance (Kinney et al, 1970). Both size-distance perception and position constancy are highly dependent on strictly visual information. Although position constancy has an obvious proprioceptive component, there is some evidence that proprioception is not involved in the adaptation process (Wallach & Kravitz, 1965b, 1968). It is therefore possible that long-term intermittent exposure to a distorted environment does not produce adaptation of primarily visual processes.

The results of this experiment indicate that distortion in the constancy of visual position should be added to the list of vision-related problems which occur in the underwater environment. These other problems include poor visibility and stereoacuity; distorted size, distance, and color perception; and distortion of hand-eye coordination (Luria & Kinney, 1970). Further research is required to determine the extent to which adaptation to distortion of position constancy occurs with specific underwater experience.

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