Size-distance invariance in perceptual adaptation*

SAMUEL S. FRANKLIN, Fresno State College, Fresno, Calif. 93720
HELEN E. ROSS, University of Stirling, Scotland
and
GERSHON WELTMAN, University of California, Los Angeles, Calif. 90024

Objects viewed through a facemask under water appear larger and closer than when viewed in air. Divers' adaptation to this distortion was measured by obtaining estimates of the size and distance of an array of targets before and after a 20-min underwater dive. A negative correlation between size- and distance-adaptation scores indicated that most divers adapted to one dimension by counteradapting to the other. For example, some Ss adapted to size by increasing the distortion of apparent distance and some the other way around. The results were discussed in relation to the size-distance invariance hypothesis.

Recent experiments by Rock (1965, 1966) have confirmed Stratton's (1903) prediction of adaptation to a size-distorted retinal image. Rock found that viewing objects through a convex mirror, which minified their retinal image but which left distance undistorted, resulted in adaptation in the direction of veridical size perception. Ross, Franklin, Weltman, & Lennie (1970) found size adaptation following a period of underwater viewing in which both size and distance are usually perceived as distorted. Underwater distortion of size and distance occurs when a diver views objects through a facemask which introduces a water-glass-air interface between the eyes and an underwater object. Since the refractive index of water is 4/3 that of air, light rays passing from water into air are refracted away from the normal. This produces a virtual image at approximately 3/4 of the object's physical distance (the location of the virtual image is referred to as the optical distance), with an angular magnification of about 4/3 that which occurs in air. These effects obtain for objects viewed normally to the mask; objects in the periphery undergo greater distortion.

According to the size-distance invariance hypothesis, there are alternative ways of perceiving the retinal image of an underwater object. An object viewed through a facemask under water should appear its correct size if perceived at its optical distance (3/4 physical distance), 4/3 enlarged if perceived at the physical distance, and proportionately enlarged if it appears between the optical and physical distance. The latter case occurs for most divers when viewing nearby objects in clear water (Luria & Kinney, 1970; Luria, Kinney, & Weissman, 1967; Ross, 1967). Since divers usually see close underwater objects as too large and too near, the conditions exist for size and distance adaptation. Adaptation on both dimensions, however, requires an inversion of the normal size-distance relation. For a given retinal angle, perceived size must decrease while perceived distance increases; an object must come to appear both smaller and further. If size-distance invariance is maintained underwater, then adaptation on one dimension would be accompanied by further distortion of the other. Size adaptation would require the object to appear even more distorted in distance and, conversely, adaptation to distance must involve counteradaptation to size. The purpose of the present experiment was to determine whether size-distance invariance is maintained during adaptation, or whether adaptation to both size and distance can occur simultaneously.

*This research was supported by the Office of Naval Research, Contract No. N00014-67-A-0111-0015 and conducted at the Biotechnology Laboratory, Department of Engineering, University of California, Los Angeles. We should like to thank Dr. Glenn Egstrom, Mr. Frank Gasser, and Mr. Peter Lennie for assistance.

†Address: Department of Psychology, Fresno State College, Fresno, Calif. 93726.

SUBJECTS

Eleven experienced SCUBA divers and 15 controls served as Ss. The divers were volunteers from an advanced diving program, and had an average of about 3 years' diving experience. The control Ss were volunteers recruited from the University campus.

APPARATUS AND PROCEDURE

Lengths of ½-in.-diam black doweling were cemented into cans various sizes, and cut to 6, 9, 12, 15, or 18 in. above the top of the can. The size of the can and the length of the doweling were matched randomly to prevent the cans from providing systematic size or distance cues. Ten dowels, two of each length, constituted a set of targets. The Ss estimated the size (height in inches) and distance (in feet and inches) of each target in air and in water, before and after a 20-min period under water.

The procedure for the diving group was as follows. One set of targets was arranged on a large paved area adjacent to the swimming pool. A rope was stretched across the area and provided a baseline from which the Ss viewed the targets, which were placed about 3 ft apart, in random order, in front of the rope at the following distances: two 6-in. targets at 15 ft, two 9-in. targets at 12 ft, two 12-in. targets at 3 ft, two 15-in. targets at 9 ft, and two 18-in. targets at 5 ft. The S, wearing a facemask, knelt at the rope in front of each target and recorded his estimates on an index card. After the air test (air pretest), the divers went directly to the pool, being careful to avoid looking into the water until submerged, and received the water pretest. With their diving apparatus on, Ss knelt at the baseline under water and estimated the size and distance of the water targets (water pretest). The water targets, arranged with the same combination of sizes and distances as in air but in a different order, were placed on the bottom of the pool in 5 ft of water about 5 ft apart. Swimming-lane lines were clearly visible, and were parallel to the S's line of sight. After completing the water pretest, the divers swam to the deep end of the pool and remained underwater for 20 min. During this period they explored the bottom of the pool, swam around freely, and stacked soft-drink cans. They then returned to the shallow end of the pool, where they again estimated the size and distance of the targets (water posttest). The random order of the targets was rearranged between the first and second water tests. The Ss then removed their diving equipment (except for the facemask) as quickly as possible, and ran to the area of the air targets, where they were tested on a rearranged sequence (air posttest). The test took about 2 min to complete in air, and about 4 min in water. About 1 min was spent after leaving the water on removing diving equipment and running to the air test area. The data cards were collected immediately after each test to prevent rehearsal of previous estimates.

The testing procedure for the control group was similar to that of the divers, except that both the air and "water" targets were estimated in air on a lawn beside a swimming pool, and the 20-min "underwater" period was spent swimming (without a facemask) or sunbathing. For each test the S recorded his estimates on a different card, which was collected at the end of the test. The order of targets for the air and "water" tests was the same as in the diver pretest conditions. The "water" targets were arranged about 20 yds away from the air targets on the same lawn. After completing the air and "water"

Table 1
Mean Size and Distance Judgments Over All Targets for Divers and Control Ss

	Air		Water*	
	Pretest	Posttest	Pretest	Posttest
Divers				
Size (In.)	12.89	12.58	13.08	12.63
Distance (Ft)	7.44	7.60	6.49	6.56
Controls				
Size (In.)	12.05	13.41	13.35	13.17
Distance (Ft)	7.41	7.40	7.76	7.55

**The "water" tests of the controls were run in air.*

pretests the Ss were instructed to occupy themselves for 20 min. They then repeated the "water" and air tests, but judged the order from right to left instead of left to right.

RESULTS AND DISCUSSION

Table 1 presents the mean size and distance estimates for the divers and control Ss in each of the four test sessions. The true mean target size was 12.0 in., and the true mean target distance was 8.8 ft. Both groups demonstrated highly similar mean estimates in the initial air test; both tended to overestimate mean target size and underestimate mean target distance. Wilcoxon matched-pair signed-ranks tests on the mean estimates (over all targets) for the control Ss showed no significant differences for either size or distance judgments between any of the four test sessions. This shows that shifts in apparent size and distance did not occur as a consequence of repeated estimates at the time intervals employed. Divers, on the other hand, showed some predictable differences between test sessions.

Air-Water Differences

Because the diver's facemask refracts incoming light rays in water, differences between air and water pretest judgments were expected. This prediction was partially confirmed. Distance judgments in water were underestimated relative to judgments of distance in air ($p = .025$; Wilcoxon, two-tailed). Air and water pretest estimates of size, however, did not differ significantly. This result would be expected from the size-distance invariance hypothesis if underwater apparent distance was at the optical distance (three-fourths of the physical distance). However, a comparison of the mean distance judgments of the water pretest with three-fourths mean air-pretest distance judgments (used as an index of optical distance) revealed that underwater targets appeared beyond the optical distance ($p < .01$; Wilcoxon, two-tailed). According to the size-distance invariance hypothesis, then, objects should have appeared larger in water than in air. While previous investigations have shown that strict size-distance invariance is not maintained in underwater vision (Luria et al, 1967; Ross, 1967), the fact that size was not overestimated in the water pretest is nevertheless slightly surprising; size overestimation under water has been observed by several investigators (Luria & Kinney, 1970; Luria et al, 1967; Ross, 1967; Ross et al, in press), and, as subsequent analyses revealed, the divers in the present experiment showed significant adaptation to size distortion. The absence of air-water size difference may be partly explained by an intellectual correction of size estimates in water. Since divers were familiar with the distorting effect of a facemask, they may have attempted to compensate for the distortion by reducing their size estimates. In addition to any intellectual correction, experienced divers may have also shown some transfer of previous perceptual adaptation immediately upon entering the water, so that they experienced less distortion than might be expected on the basis of optical stimulation (Luria & Kinney, 1970; Ross, 1970, Ross et al, in press).

Size-Distance Adaptation

The relation between size and distance adaptation was examined in two ways. First, comparisons of pre- and posttest judgments were made to determine whether adaptation occurred to size or distance or to both. If the normal size-distance relation is maintained during adaptation, then an adaptive shift to one dimension and a counteradaptive shift to the other would be expected. Second, a correlational analysis was performed on the water pre- and posttest difference scores of each dimension. If size-distance invariance is maintained, an inverse correlation between the difference scores should obtain: a shift in the direction of size adaptation should be accompanied by a counteradaptive shift to distance and vice versa.

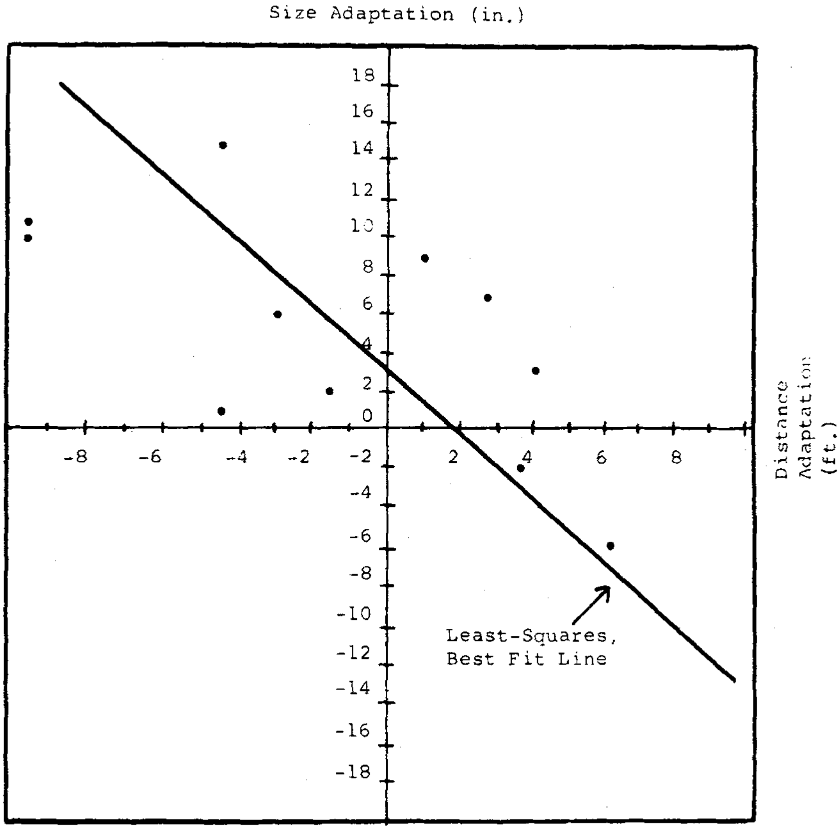

Fig. 1. Scatter diagram showing negative correlation between size and distance adaptation. The adaptation scores are the difference scores between the sums of the water estimates in the pre- and posttests. Positive scores indicate an adaptive shift, negative scores a counteradaptive shift.

Pre- and posttest comparisons were performed on both water and air estimates (the latter measures the aftereffect of adaptation). Size estimates in the water posttest were significantly smaller than in the pretest ($p < .025$; Wilcoxon, one-tailed). The air posttest estimates were not significantly different from the air pretest judgments. The failure to find significant adaptation as measured by the aftereffect was not unexpected. The aftereffect is known to fade rapidly (Dewar, 1970; Ross et al, in press) and could easily have dissipated while the diver left the pool, removed his diving gear, and ran to the air test site. Although the data clearly indicate distortion of distance under water, a pre- and posttest comparison failed to reveal any adaptation to this distortion. The posttest judgments tended to be larger than pretest judgments, both in water and in air, but these differences were very small and did not approach significance.

The analyses of the pre- and posttest difference scores (in water) at first suggested that, on the average, divers adapted to size but did not alter their distance judgments. These findings are not consistent with the strict form of the size-distance invariance hypothesis, which predicts counteradaptation to distance in proportion to the degree of size adaptation. However, an inspection of the data revealed that the pre- and posttest comparisons may not adequately reflect the results. If some Ss adapted to size (by further distorting distance) and some Ss adapted to distance (by further distorting size), then the average pre- and posttest difference score on each dimension would be appreciably reduced. Therefore, a more appropriate analysis of the relation between size and distance adaptation was performed. A Spearman rank-order correlation on the size and distance adaptation scores (total pre- minus total posttest differences) of the water tests revealed a significant negative correlation (rho = −.71, $p < .025$), indicating that size adaptation was indeed inversely related to distance adaptation. The same analysis for the control Ss showed no relation between these two sets of difference scores (rho = −.17). The relation between size and distance adaptation is shown in Fig. 1: divers who adapt on one dimension tend to counteradapt on the other. Of the 11 divers, 8 demonstrated this effect, 6 adapting to size while counteradapting to distance and 2 the other way around. It is noteworthy that the three remaining scores fall in the upper right-hand quadrant of the figure, suggesting that adaptation to both size and distance may be possible.

The correlational analysis suggests that for most divers, adaptation to size and distance does not occur simultaneously. Rather, adaptation on one dimension tends to be accompanied by further distortion of the other. Adaptation to size was accompanied by further distortion of distance and vice versa. Although these findings do not necessarily imply strict proportionality of the size-distance relationship, they do indicate that at least a weak form of size-distance invariance is maintained during adaptation. The results also suggest the hypothesis that adaptation to distortion can have the effect of providing both increased and decreased correspondence between perception and the environment.

REFERENCES

DEWAR, R. Adaptation to displaced vision: The influence of distribution of practice on retention. Perception & Psychophysics, 1970, 8, 33-34.

KINNEY, J. A. S., LURIA, S. M., & WEITZMAN, D. O. Responses to the underwater distortion of visual stimuli. USNSMC Report No. 541, U.S. Naval Submarine Base, Groton, Connecticut, 1968.

LURIA, S. M., & KINNEY, J. A. S. Underwater vision. Science, 1970, 167, 1454-1461.

LURIA, S. M., KINNEY, J. A. S., & WEISSMAN, S. Estimates of size and distance underwater. American Journal of Psychology, 1967, 80, 282-286.

ROCK, I. Adaptation to a minified image. Psychonomic Science, 1965, 2, 105-106.

ROCK, I. *The nature of perceptual adaptation.* New York: Basic Books, 1966.

ROSS, H. E. Water, fog, and the size-distance invariance hypothesis. British Journal of Psychology, 1967, 58, 301-313.

ROSS, H. E. Adaptation of divers to curvature distortion under water. Ergonomics, 1970, 12, (in press).

ROSS, H. E., FRANKLIN, S. S., WELTMAN, G., & LENNIE, P. Adaptation of divers to size distortion under water. British Journal of Psychology, 1970, 61, 365-373.

STRATTON, G. M. *Experimental psychology and culture.* New York: Macmillan, 1903.

TSD and coding in STM

JOHN M. ACKROFF* and RICHARD O. ROUSE, JR.†

Williams College, Williamstown, Mass. 01267

Ss were asked to listen to a list of words and to identify repeated words upon hearing them. Interspersed with the repetitions were words that were associatively or acoustically related to the repeated words. The intrusion errors were analyzed and the differences across word class found to be highly significant; application of signal-detection theory provided a means of quantifying this difference.

Marshall, Rouse, & Tarpy (1969) present a summary of previous work in the field of coding strategies in STM. Of special interest for their study, and for the present one, are the works of Conrad (1962, 1964) and Wickelgren (1966), which present an acoustical model for STM, and Schwartz & Rouse (1961), which postulates an associative model.

Broadbent & Gregory (1963) used signal-detection theory (TSD) to study attention. Digits were presented to one ear while bursts of noise were presented to the other; application of TSD allowed Broadbent and Gregory to determine the separation between the noise (N) and signal-plus-noise (SN) distributions. Murdock (1965) also used TSD in a memory task, using recognition of paired associates. After being presented with a series of PAs, Ss were to determine whether each of another set of PAs had been seen before; application of TSD allowed Murdock to analyze the types of intrusion errors that were made.

The purpose of this experiment is to

*National Science Foundation Undergraduate Research Participant.

†Please address requests for reprints to Professor Richard O. Rouse, Jr., Dept of Psychology, Williams College, Williamstown, Mass. 01267.