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ADAPTATION TO VISUAL AND NONVISUAL REARRANGEMENT

by Sidney Weinstein, Milton Richlin, Marvin Weisinger, and Larry Fisher

Prepared by
YESHIVA UNIVERSITY
Bronx, N. Y.
for

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Abstract

A series of experiments was performed to investigate the roles of various types of informational feedback in producing visual adaptation to visual rearrangement and to various head, eye, and arm positions. A major goal was to test the validity of the theory of reafference which states that self-induced movement is essential in the production of visual adaptation to rearrangement.

In the first study, four groups of subjects who wore laterally-displacing prisms, moved in a wheelchair through a corridor for one hour in the following manners: (a) self-guided and self-propelled, (b) self-guided but propelled by a nonguiding (blindfolded) experimenter, (c) guided by the experimenter but self-propelled, and (d) guided and propelled by the experimenter. All groups yielded significant, nondifferential, positive adaptation after exposure in the egocentric localization task.

In a second study, seated subjects, with head motion eliminated by a bite-bar, wore laterally-displacing prisms. By directing the experimenter, the subject controlled rotation about his vertical axis while attempting egocentric localization. After each trial during the 30 minute period, the experimenter rotated the immobile subject to the "true" zero point (determined by prior nonprism trials). The experimenter thus provided information concerning the degree of mislocalization. The results showed significantly positive mean adaptation for the group.

Disarrangement of eye-hand coordination was next studied by employing a displacing mirror. We failed to replicate Held and Schlank's results, and thus failed to support reafference theory. We then repeated our study, utilizing subjects as their own controls, and again confirmed our finding that information obtained under passive conditions is at least as effective as reafference, and possibly more so, in producing positive adaptation.

In the next study, we employed a variation of the Wallach, Kravitz, and Lindauer technique for producing adaptation to prisms. The erect, stationary subject observed his lower extremities for 10 minutes through laterally-displacing prisms. Immobilizing his head by means of a bite-bar served to eliminate reafference from head movement. The results of the egocentric localization task confirmed the Wallach, et al. finding of significant positive adaptation in the absence of reafference. Several subjects demonstrated 100% positive adaptation. We then modified our procedures requiring eight exposures for all subjects and repeated the experiment. The proportions of subjects adapting positively were almost identical in the two studies, however, 100% adaptation was not obtained in the replication.

A final study was initiated in the attempt to determine whether positional or other nonvisual factors can function in the production of visual adaptation. A secondary goal was the analysis of effects of prismatic refraction by isolating displacement from extra-displacement effects. The results clearly indicated visual adaptational effects dependent upon: (a) lateral displacement of the visual image, (b) extra-displacement effects of prismatic refraction, (c) eye and head positions, and (d) hand preference or direction of motion.

This series of experiments has consistently indicated that even brief experience with prismatic refraction can produce visual adaptation in the absence of self-induced movement. The results point to the influence upon visual perception of informational feedback derivable from nonvisual factors (body, head, and eye positions) as well as from visual information. If, as we believe, nonvisual channels are important in visual adaptation, then these findings indicate the value of studying the role of intermodal sensory effects upon sensation and perception in all modalities.

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Introduction

It has been pointed out (Held and Freedman, 1963) that perceptual-motor tasks which will be performed in space by astronauts may require such performance under "unusual" conditions. Minimally, these changed conditions will include zero gravity, wearing a space suit and breathing pure oxygen. Additionally, the astronaut will have been under varying amounts of sensory deprivation, movement restriction, etc.

There remains, however, another category of possible disturbance of performance, sensory rearrangement. This term is used in perceptual research to describe the experimental alteration of the normal sensory input to an organism. Most recent work employed laterally-displacing prisms, and was concerned with determining the effect of wearing prisms by measuring visual-motor adaptation to the prisms. Other forms of rearrangement have been employed by Witkin, et al. (1954), Kohler (1951), Werner and Wapner (1952), and Smith and Smith (1962).

Held, a major investigator in the area of prism rearrangement, has proposed a theory which maintains that adaptation to a rearranged visual world can occur only when the organism is responsible for the changes in his visual stimulation. Thus, Held and Freedman (1963) state that, "Essential for the stability of many of the plastic systems is the order entailed in the relation between the natural movements of an individual in his environment and their consequent sensory feedback. . . . The central nervous system of the observer is both the originator of the movement and the receiver of its consequent sensory feedback. The central nervous system may be assumed to retain information concerning the output signals and to be informed of the dependent input signals. . . this information has an important function above and beyond its use in spatial discrimination. It is necessary (italics added) for maintaining and for altering the response characteristics of the sensorimotor control system in humans and certain other higher mammals" (Held and Freedman, 1963, p. 1).

In describing his theory, Held employes the term, "reafference" which is defined as, ". . . fedback stimulation correlated with the self-produced movements of the stimulated organism" and which is " . . . essential for readjustment of visual-motor coordination during rearrangement" (Hein & Held, 1962, p. 71).

It seemed to us that the experiments which had uniformly supported this theory (Held & Bossom, 1961; Held & Schlank, 1959; Held & Hein, 1958) might not have provided an environment sufficiently rich in information or a sufficiently vigilant S in order to evaluate their "passive" condition. Consequently, we instituted a series of experiments on the assumption that adaptation to a visually-rearranged environment results from information on the rearranged environment being fed to the individual. We further assumed that the source of this information need not be self-induced movement (reafference). In these experiments the effectiveness of informational feedback in producing adaptation was compared to the degree of adaptation resulting from the effects of self-induced movements

This report presents an exposition of these experiments, in chronological sequence.

Adaptation to Laterally Displacing Prisms

Active Versus Passive Locomotion

An interesting study yielding data favorable to reafference theory has been reported by Held and Bossom (1961). In this study, the active, or reafferent group wore 20-diopter (11°) laterally displacing prisms while walking about a campus for one hour. The passive group wore the same prisms for one hour, but were transported over the campus pathway in a wheelchair, propelled and guided by E.

Their results indicated significant adaptation to prisms for the active group only. In our experiment, (Weinstein, Sersen, Fisher & Weisinger, 1964) all Ss wore 13-diopter (7.4°) prisms and used a corridor in a hospital as the pathway, rather than an outdoor path. We employed four groups, all exposed to the prisms for one hour while in a wheelchair: 1. A self-guiding and self-propelling group, equivalent to Held & Hein's active group; 2. A group equivalent to their "passive" group, who were moved through the corridor in a wheelchair propelled by E;

3. A self-guiding group who were propelled in the wheelchair by a blindfolded E with S controlling the direction of movement by verbally instructing E when to turn, stop, etc.; 4. A self-propelled group who rotated the wheels of the wheelchair, but for whom all guidance was provided by E.

"Apparatus. The apparatus consisted of a swivel chair situated in the center of 235° of a cylinder of white satin, 6 ft. in diameter X 50 in. high...The target consisted of a vertical black line, 2 in. by 1/16 in., fixed to the cloth.

"Vertical blinders fixed to the chair limited S's horizontal visual angle to approximately 80° at all times. A movable lower horizontal blinder and a fixed top blinder excluded all but the cylindrical field from S's view. S's head was fixed securely in place by means of a bite bar, consisting of dental wax in a plastic dental base plate mold. Even at the extreme positions of rotation, the resulting field of view was a white field with a vertical target.

"An adjustable protractor attached to the rotating shaft of the chair could be read from the rear...The protractor could be set to zero regardless of the orientation of the chair, and any rotation of the chair could be read in 0.1° left or right of the arbitrary zero " (Weinstein, Sersen, Fisher & Weisinger, 1964, p. 642).

"Procedure. Two tests of egocentric localization were administered to each S. For the first test no prisms were used while for the second test S wore 13 prism diopter wedge prisms which produced lateral displacement of 7° 25'. Half the Ss wore base left prisms and the other half base right prisms. Following these tests, S, wearing prisms, sat in a wheelchair under one of four conditions for one hr., the same interval employed in the Held and Bossom study (1961). There were 48 Ss randomly assigned, 12 to each of the four conditions. Immediately after the experience with the prisms, each S was retested, first with the prisms and then without.

"In the pre-exposure test S sat in the test chair and imbedded his teeth in the bite bar. He then attempted to orient himself with respect to the line so that it apparently bisected his body. S accomplished this by moving the chair with his feet. Before the first judgment, E rotated the chair so that it was left of the line and S was allowed as much time as necessary to orient himself. Once the first judgment was made, the protractor was set at zero and all future judgments for that S were measured as deviations from that point. Before each judgment, E placed the chair randomly between 30° and 50° from zero, alternating left and right on succeeding trials. Six judgments were made without prisms followed by six judgments with prisms; the mean of each set of six judgments represented the score for that test.

"For all exposure conditions S sat in a wheelchair and wore the same prisms with which he had been tested.

"...In the postexposure test S returned to the test chair and bit into the bar... The previous testing procedure was employed except that no new zero point was taken and the order of testing was reversed, i.e., six judgments were first made with the prisms on followed by six judgments without the prisms " (Weinstein, Sersen, Fisher & Weisinger, 1964, pp. 643-644).

Results. The results of this experiment can easily be summarized: all four groups showed significant but nondifferential positive adaptation to the prisms. It is interesting to note that even the order of magnitude of adaptation of the groups, although not significantly different, failed to agree with what would be predicted from reafference theory. Thus, the order of magnitude of adaptation of the groups, from greatest to least, was: self-guiding (1.09°), self-guiding and propelling (1.06°), self-propelling (.77°), passive (.72°).

Informational Feedback in Egocentric Localization

In a second study (Weinstein, Sersen, Fisher & Weisinger, 1964) we utilized the testing apparatus of the study described above as a means of providing S with prism exposure under conditions in which even the possibility of slight head movements was eliminated. A foot rest was attached to the test chair, eliminating foot movements, and the 2-in. target line was replaced by a blue rod, 1/16 in. in diameter, extending the height of the field and 1 in. in front of it. Only the cylindrical field and target were visible at all times.

"Procedure. Each (of 17) Ss was tested for egocentric orientation without prisms before and after 30 min. of prism exposure. Eight Ss had base-left and nine base-right prisms.

"In the pre-exposure test S sat in the chair, with his feet on the footrest, and bit into the bite bar... S was required to orient himself so that the line appeared to bisect the frontal plane of his body. This was accomplished by E's rotation of the chair in response to gestures of S's index finger. The first judgment was again used to set the zero point. The starting position for the chair was alternated 30° to 50° left and right on each succeeding trial. The mean of eight judgments constituted the pre-exposure test score.

"During the exposure period S was still immobilized by the bite bar, prisms were put in place, and he continued making judgments in the same manner. However he was instructed that following each judgment, E would now rotate the chair to the "true zero" point, indicating his error and enabling him to correct further judgments. The "true zero" point was set at the mean of S's eight pre-exposure judgments. As before, the starting position of the chair was alternated left and right. S continued making judgments for 30 min.

"For the postexposure test the prisms were removed and S made eight judgments in the same manner as he did before exposure. The mean of these eight judgments constituted the postexposure test score." (Weinstein, Sersen, Fisher & Weisinger, 1964, p. 646).

Results and Discussion. "The results clearly demonstrated significant positive adaptation in the absence of self-induced movement for the group as a whole, as well as for seven individual Ss. Although it might be argued that there was only a minor degree of adaptation, i.e., our group had a mean of 14.3% positive adaptation, the mean adaptation obtained in the Held and Bossom study (1961) was only 11.4%. Furthermore, the greater adaptation of our Ss was obtained after only one half hour of exposure, in contrast to one hour for their Ss. In addition, the maximum individual adaptation in the present study was 65.9%, whereas the maximum in the study of Held and Bossom (1961) was 37.1%, a figure exceeded by 18% of our Ss.

"These results again seem to cast serious doubt upon the assertion that reafference is a necessary condition for adaptation. Indeed, since we have shown that reafference is not necessary, and that informational feedback is sufficient for adaptation, it is conceivable that the sole effect of reafference may depend upon its concomitant informational feedback" (Weinstein, Sersen, Fisher & Weisinger, 1964, pp. 647-648).

Adaptation to Mirror Displacement

An Attempt to Replicate a Study of Disarranged Eye-Hand Coordination

We next attempted to replicate a study by Held and Schlank (1959). In this experiment (Weinstein, Sersen, & Weinstein, 1964) we attempted both replication and an additional comparison in which informational feedback was enhanced.

"Three groups of 15 Ss each were tested for disarranged eye-hand coordination in the distance dimension. All groups were tested using a bipartite box which permitted lighting only the upper or lower chambers. S was required to place a dot at the location of a virtual image of a target without seeing his hand. After making 30 such dots he was exposed to one of three conditions, after which he repeated the pre-exposure test. The three conditions were: (a) constrained self-produced hand movement with 7.6 cm. displacement, (b) free hand movement with 7.6 cm. displacement, (c) free hand movement without displacement (control). The results indicated a predominant proportion of individuals with negative adaptation in all groups. The two groups with reafference (stimulation through self-induced movement) and displacement, did not differ significantly from the control group in the magnitude or the direction of adaptation." (p. 629).

"We cannot account for the fact that the control group yielded significant negative adaptation without any visual displacement. Even more perplexing is the finding that reafference, i.e., stimulation from self-produced movement, not only failed to produce positive adaptation, it even failed to produce less negative adaptation than the control condition. Since we do not believe that the minor procedural differences between our experiment and that of Held and Schlank were critical to the difference in the results of the two studies, we concluded that we failed to replicate the results of Held and Schlank, showing that reafference produces adaptive shifts to mirror-disarranged eye-hand coordination" (P. 632).

In commenting on this experiment, Held & Schlank (1964) indicated that our use of independent groups had so increased the variability that demonstration of significant adaptation in general was unlikely. We accepted their suggestion of using each S as his own control and essentially repeated the experiment.

Another Attempt to Replicate a Study of Disarranged Eye-Hand Coordination

Subjects and Apparatus. There were 18 Ss employed, comprising laboratory technicians, secretaries, and undergraduate and graduate students in psychology, ranging in age from 21 to 31 (M = 23.6). All were naive concerning the purpose of the experiment. The apparatus was a replica of Held and Schlank's (1959), which, essentially, consisted of a bipartite box in which either the upper or lower half was independently illuminated. This device had also previously been employed in a previous study at this laboratory (Weinstein, Sersen & Weinstein, 1964). When the upper half was lighted, S saw a virtual image of a target; when the lower half was lighted, S saw the image of his hand displaced 7.6 cm. distally. The mirror in which S saw his hand was adjustable so that it could be removed by E enabling S to see his actual hand. The contour headrest and very small peep holes insured only minimal head or eye movements.

In all conditions for pre- and postexposure testing, the upper chamber of the testing box was illuminated to enable S to see the target and the lower chamber darkened. For exposure, between pre- and postexposure testing, the lower chamber was illuminated to permit S to see his hand and the upper darkened. In this condition, the hand was either seen normally (mirror moved out of position) or mirror-displaced by 7.6 cm. Three letters (A, B, C) were engraved on the left side of the bottom surface of the testing box, 10 mm. apart along the distal dimension. To the right of each letter were small horizontal centered lines.

A-

B-

C-

The purpose of these letters was to have S judge his hand position during exposure.

Procedure. At the beginning of testing, S looked into the box and was asked to place 30 dots with a sharpened pencil at the virtual image of a target. He reached inside the box with his unseen hand, made a dot, and removed his hand after each response. Following the pre-exposure testing, S was exposed to one of three conditions and then retested as before, i.e., he again placed 30 dots. There were three conditions of exposure; S was tested once daily under one of the three conditions. For 16 Ss three successive days were employed to test the three conditions; for 2 Ss a weekend intervened between two of the conditions. Three Ss were tested for each of the six permutations of the three conditions (18 Ss).

The three conditions of exposure were as follows. In the Reafference Condition (displacement and self-produced hand movement) S's pronated hand was strapped to a board, which moved on tracks in the median plane, 7.5 cm proximally and distally. S made each hand movement to the beat of a metronome set at 40 beats per minute for six minutes, (240 beats). S viewed his actually moving hand for six minutes. After this, his hand was unstrapped from the board, the upper chamber was illuminated and the lower darkened, and postexposure testing begun. In the Informational-feedback Condition (displacement and passive movement) S's hand was strapped to the board as above, except that this time his hand was moved passively by E to the same metronome beat for six minutes. In the Control Condition, S's hand was also strapped in the same manner, and he moved his hand as he did in the Reafference Condition. However, in this condition, the mirror was rotated out of position, so that S saw his actual, rather than his displaced hand.

In order to insure that S was actually carefully observing his hand, he was instructed to perform a task. Before the six minutes of exposure of the displaced or actual hand, a pencil mark was made on either the distal or the middle phalanx of the middle finger of S's hand. During the six minutes of exposure in each of the three conditions S was required to observe the coincidence of the line on his finger with the A, B, or C line. Thus, on most of the backward movements of the hand in the apparatus, E named one of the three letters. On moving his hand distally S was required to say "Now" when the mark on his finger was in line with the appropriate letter. He was instructed that he would be given a ten cent reward for each accurate judgment made. This procedure was employed in all conditions to motivate S to observe his moving hand carefully during the entire six minutes.

The following instructions were read to S before and after each of the three exposures, for pre- and postexposure testing.

"Look inside the box. You will see an image of a circle with a cross inside. Do you see the circle and cross? Keep your pencil vertical, and reach inside the box, placing a dot at the exact point of the center of the cross. At each count make a dot. Remove your hand from the box after each dot and place it at your side. I will count 30 times; you will make 30 dots; any questions? Ready? One."

The following instructions were read after the dotting was completed and before each of the three six-minute exposure periods. The bracketed words were added (or replaced the appropriate pronoun) for the Passive (Informational-feedback) Condition; the unmodified instructions were read before the Reafference and the Control Conditions.

"[We will] Slide the board forward inside the box until it stops at the end. Then [we will] slide it back until it stops. [We will] Move it at each beat of the metronome. [Let us] Practice this a few times without looking inside the box. Now look inside the box, you will see your hand and three letters - A, B, C. Your task will be to tell me when the line on your middle finger lines up exactly with the letter I will call out in advance.

"I will call out a letter when you [I] move your hand backward. Say 'Now' when your finger and that letter line up exactly. You will be given ten cents for each exact judgment at the end of the entire experiment. Any questions? Ready? Let's begin and continue until I say 'Stop.'"

Results. Table 26 gives the summary of the analysis of variance for Conditions (Reafference, Informational-feedback, and Control), Pre- versus Postexposure, and Order of testing. None of the primary variables was significant; however, the triple interaction was significant, indicating differential effects of exposure among the groups within the various orders of testing. A matrix of t tests between the three Conditions was done within each of the six orders for the difference in adaptation before and after exposure.

Table 26

Summary of Analysis of Variance for Adaptation Under Conditions of Exposure and Order of Testing

Source	df	MS	F
Between Ss	17	20,273.30	
Orders	5	21,502.96	1.09
Ss within gps	12	19,760.95	
Within Ss	90	437.40	
Pre-Post	1	689.10	<1
Condition	2	807.40	1.33
Pre-Post x Cond.	2	242.50	2.44
Order x Pre-Post	5	790.60	1.72
Order x Cond.	10	791.50	1.31
Order x Cond. x Pre-Post	10	227.96	2.29*
Pooled Ss x Order Pre-Post	60	337.80	
S x Pre-Post	12	459.10	4.62**
S x Cond.	24	605.10	6.09**
S x Pre-Post-Cond.	24	99.40	

* $p < .05$, ** $p < .01$

The only significant differences ($p < .05$) appeared between the following groups in these orders of testing. (a) Order 2 (C-IF-R): IF produced significantly less negative adaptation than C; (b) Order 4 (R-IF-C): C and R produced significantly more positive adaptation than IF; (c) Order 6 (IF-R-C): IF produced significantly more positive adaptation than R or C.

In general, ignoring order, the C and R Conditions produced negative and IF positive adaptation. If the mean of the Control Condition is subtracted from the means of the two experimental conditions the respective mean positive adaptations resulting are: R=5.1 mm (7%), and IF=10.4 mm (14%).

Under the assumption that exposure to some form of visual displacement may carry over to subsequent conditions of testing, an analysis of variance was performed in which the postexposure score from each condition was compared with the first pre-exposure score obtained regardless of which condition it preceded. The analysis concerned the two variables: Order and Condition, with the score being the pre-exposure-postexposure difference. Table 27 gives the summary of this analysis.

Table 27
Summary of Analysis of Variance for Conditions and Order of Testing

Source	df	MS	F
Between Ss	17	2670.6	
Order	5	3889.0	1.80
Ss within gps	12	2163.0	
Within Ss	36	374.7	
Conditions	2	1320.8	4.51*
Cond. x Order	10	381.8	1.30
Ss x Cond.	24	292.9	

* $p < .05$

It can be seen that Conditions produced significantly different adaptation. The t tests performed indicated that the IF and C Conditions differed significantly ($p < .01$); none of the other comparisons were significant. The mean adaptation of the Conditions was as follows: C = -4.43 mm. (-6%); R = 3.80 mm. (+5%); IF = 12.70 mm. (+17%). If the percentage of adaptation of the two experimental conditions are taken as differences from the Control Condition, rather than from zero, the degrees of adaptation of the R and IF Conditions are 11% and 23% respectively.

Discussion. As Held and Schlank (1964) had predicted, using the same Ss in all conditions reduced the variability considerably, and significant adaptation was obtained under the Reafference Condition. However, the passive condition (Informational Feedback) also produced significant adaptation. Indeed, it produced more positive adaptation than did Reafference.

We must, therefore, conclude that we have failed once more to confirm the results reported by Held and Schlank (1959). Furthermore, we have again demonstrated the sufficiency of informational feedback, through a passive condition, to produce adaptation to a displaced visual field. This finding, obtained with mirror-displacement, agrees with our previous findings based on prism-displacement, that reafference is not a necessary condition for visual adaptation, and may actually be less efficient than other forms of informational feedback in adapting to a visually-rearranged environment.

Adaptation to Prisms in the Absence of Movement

In 1963, Wallach, Kravitz and Lindauer reported an experiment in which large degrees of adaptation to prisms was shown by Ss after brief (10 minute) exposure under "passive" conditions. In that study, rather than employing immobilization, Ss were merely instructed not to move. Since Held and his associates had recently taken the position that "full and exact compensation" could only take place under reafference conditions (Held and Freedman, 1963), we decided to replicate the Wallach, et al. experiment utilizing more precise controls and specifically immobilizing the head.

Procedure

We employed 46 Ss (30 men and 16 women): medical technicians, medical students, physicians, nurses, and other hospital employees. The apparatus consisted of an adjustable bite-bar, target light, and protractor all adjustable to S's height. The dim target light above the protractor, was located approximately at S's eye level, 61 cm. from the right eye. The protractor, the pointing surface for S, was attached 17.8 cm. below the target light and parallel to the floor. S bit into the bite-bar, an aluminum bar 2.5 cm. wide, covered with dental wax. His left eye was occluded with an eye patch, a pointer was attached to his right index finger, and the room was darkened. E then raised a curtain revealing dim target light. S attempted to place his right index finger on the lower surface of the protractor directly below the light. After each judgment, S closed his eyes while E recorded the position of the pointer to the nearest 0.5°. Following the judgment, S returned his right arm to his side. The mean of ten such judgments constituted the pre-exposure score.

Following the ten pre-exposure judgments, the room was illuminated and the bite-bar was rotated 90° downward, enabling S to see his feet. The eye patch remained in place over the left eye, and a 13-diopter base-left (or base-right) laterally displacing prism was placed over S's right eye. S then observed his feet for ten minutes. Following this exposure, S closed his eyes while the prism was removed and the bite-bar was returned to its original position. The room was again darkened, and the pointing task was repeated for four trials. The mean of these four judgments constituted the postexposure score. The exposure period and the postexposure testing were repeated from one to ten additional times. Most of the Ss who continued beyond three trials required one or more rest periods. During the rest period, S sat in a chair with eyes closed for approximately 5 min.

Testing was discontinued from one to seven trials after S achieved 100% adaptation, or failed to approach 100% adaptation in several trials. Testing was also discontinued if S became ill (fainted, became dizzy, or nauseated) or was otherwise unwilling to continue.

Results

The purpose of this experiment was to determine whether "full and exact compensation" to prismatic displacement could be achieved in the absence of movement of the head or body. Such compensation was demonstrated by eight Ss. The remaining Ss did not reach 100% adaptation in the time allowed.

An analysis of variance was computed on the data of each S, comparing his pre- and postexposure means. Utilizing the pooled variance, a Dunnett's test compared each postexposure mean with zero per cent adaptation (pre-exposure mean) and with 100% adaptation (pre-exposure mean plus 7.42°).

In addition to the 8 Ss reaching 100% adaptation, 15 Ss achieved adaptation significantly greater than zero, ranging from 18% to 90%. Of these 15 Ss, 4 achieved adaptation which did not differ significantly from 100%.

All 15 Ss who achieved positive adaptation did so within three ten-minute exposure periods, 6 within the first trial. Of the 8 Ss who achieved 100% adaptation, 2 each achieved it within trials two, three, four, and five. Of these 8 Ss, 7 achieved significant positive adaptation by the first trial, the other by the third trial.

Eight Ss (17%) achieved 100% adaptation after prismatic exposure, despite the fact that the procedure employed was a difficult one for S to maintain, and caused several Ss to withdraw because of the extreme discomfort. Furthermore, not only was "full and exact" adaptation in the absence of reafference demonstrated, it was achieved after relatively brief periods of exposure. Thus, all 8 of the Ss achieving 100% adaptation did so within 30 minutes of exposure time; by contrast, the 8 Ss in the Held and Bossom study (1961), for example, required from a minimum of one hour to twenty-three hours of exposure extending over four days to achieve 100% adaptation. Similarly, the Ss of Hay and Pick (1963) required several days of reafference to achieve high levels of adaptation to prisms.

Since demonstration of 100% adaptation without reafference was the critical test of the theory, only Ss who demonstrated rapid increments of adaptation were tested repeatedly. The possibility that continued exposure trials for those Ss who did not show an early rapid rise in adaptation might have resulted in 100% adaptation was demonstrated by one S who had negative adaptation for trials one and two, but achieved 90% positive adaptation by the fourth trial, a value not significantly less than 100%.

We believe that the present procedure may have provided a more efficient means of informational feedback than those previously employed. The discrepancy between the displaced view of one's own feet and long established postural cues would be expected to provide maximal information concerning the displacing nature of the prisms and, indeed, did yield "full and exact compensation."

Although it had been recognized that other factors may be responsible for minor degrees of adaptation, it was emphasized that for full and exact compensation, *reafference is crucial.* (*Held and Freedman, 1963*) *The results of the present study,* however, have shown that informational feedback independent of reafference can also produce full and exact compensation, and thus again, support our position that reafference is only one among many sources of information sufficient to produce adaptation.

Replication: Adaptation to Prisms in the Absence of Movement

After completing the experiment described above, however, it was felt that certain of the testing procedures may have produced an experimental bias in the study. Thus, if Ss were responding in accordance with a "random walk" model, then rejecting Ss who showed negative or minimal adaptation, might have led to a biased selection of Ss who showed large amounts of positive adaptation, although the true direction of adaptation for the overall group might be zero. Consequently, we repeated the experiment with 48 additional Ss who were tested for eight trials, regardless of their degree or direction of adaptation. The apparatus was identical to that used in the study described above, with the following changes in the experimental procedure: All Ss were required to complete eight trials. No Ss were eliminated by E, and data from those Ss who could not complete eight trials were not employed. In addition, rest periods of five minutes were introduced after trials 3 and 6. S wore a blindfold during these rest periods.

The results of this additional experiment showed that of the 48 Ss, 33 demonstrated positive adaptation, 14 demonstrated negative adaptation, and one demonstrated zero adaptation. The chi-square between the number of positive and negative adaptors was 7.68 ($p < .01$), indicating a significantly greater number of positive over negative adaptors, and evidence against a "random walk" hypothesis. It should be pointed out, however, that unlike the first study in which we found eight individuals who showed complete compensation for the prisms, none were found in this second study. We cannot presently account for this discrepancy between the studies.

It is interesting to note the similarities, however, shown in Table 28. It should be pointed out that since the proportion of positive to negative adaptors was almost identical in both studies, the criticism of biased selection by early elimination of poor or negative adaptors cannot easily be made. Although Study 2 did not yield any cases of 100% adaptation, 8 such cases were obtained in

Table 28

Number of Ss Showing Positive or Negative Adaptation

Studies	N	Adaptation		
		Positive	Negative	Zero
First Study	46	32	14	0
Second Study	48	33	14	1

Study 1 and the differences in procedure were not relevant to the theoretical positions of reafference and informational feedback. We are, therefore, confident in our conclusion that we have demonstrated once more the necessity of informational feedback and lack of necessity of reafference in adaptation to prisms.

Nonvisual Factors in Adaptation to Prismatic Rearrangement

The investigations conducted in this laboratory on adaptation to rearranged environments have indicated that there may be nonvisual factors such as head position, neck torsion, etc., which are effective in producing adaptation to visual rearrangement. It is believed that such vestibular, proprioceptive, and kinesthetic factors may be operating as important informational sources in producing adaptation. The investigations of Harris (1963), Hamilton (1964) and Klein, et al. (1964) have also clearly indicated the relevance of such cues in adaptation.

A study was initiated, therefore, in which we attempted to analyze various visual and nonvisual factors that might affect adaptation.

Sample and Procedure

The Ss comprised 180 college students, (97 males, 83 females) who ranged in age from 16 to 53 years (M = 20.6). They were divided randomly into 18 groups of 10 each and each group was exposed to one of 18 conditions. The apparatus consisted primarily of two units, one used for the exposure conditions, and the other for the test conditions. The exposure unit consisted of a wooden headpiece which was attached to a fixed chestplate such that the headpiece could be rotated in the horizontal plane. A bite-bar and head-strap in the headpiece and a set of straps attached to the chest plate restricted movement of the head with respect to the headpiece and of the shoulders with respect to the chestplate. Outside the headpiece, directly below an eyehole, was a platform which supported an optical device. This device comprised either a laterally displacing 8° refracting prism, or a set of reflecting prisms producing lateral displacement of 8°. In addition, for some conditions, there was no optical device. Instead, S wore an eye-patch which occluded all vision, or an eye-patch with a pinhole which limited and directed vision.

The spatial localization device consisted of a metal bar 61 cm. in length with a bite-bar at one end and a protractor 61 cm. in radius at the other. On the protractor were mounted three (3 volt) bulbs at eye level at 0°, 10°, and 20° right of the midsagittal plane of S. The localization and exposure units were situated within two meters of each other so that S could quickly be moved from one to the other. Both the exposure and localization apparatus were individually adjusted for S prior to testing. S's left eye was occluded with an eye-patch which remained in position for the entire experimental session. All testing and exposure employed the right eye. Pre-exposure testing was as follows: S was placed in position at the bite-bar of the localization device; after the room lights were turned off, S was told to open his eyes and to point directly below the dimly lit bulb with the index finger of this right hand. The position of the finger was read from the protractor, to the nearest .5°. The procedure was repeated for twelve trials, consisting of four random presentations of the three positions of the light. The mean of these twelve judgments comprised S's pre-exposure spatial localization score.

Following the pretesting, S was placed in the exposure unit.* He was told that for ten minutes he would, on command, be asked to pick up one of five pegs

*It must be pointed out that some difficulties were encountered in testing. Thus, there were some Ss whose height made it difficult to adjust the apparatus properly. As a result, There was some variation in the placement of the objects.

(distinguishable by different tops) with his right hand, bring it back toward his chest, and then return it to its initial position. The objects were placed approximately in the center of S's visual field. E called out the objects in a random order at a rate of about one every 6 sec. The various exposure conditions are presented in Table 29.

Table 29

Exposure Conditions

1. Head turned 8° to the left; refracting prism (A) displacing 8° to the left.
2. Head turned 8° to the right; refracting prism (A) displacing 8° to the right.
3. Head turned 8° to the left; reflecting prism set (B) displacing 8° to the left.
4. Head turned 8° to the right; reflecting prism set (B) displacing 8° to the right.
5. Head turned 8° to the left; eye centered in head, using center pinhole in eye-patch.
6. Head turned 8° to the right; eye centered in head, using center pinhole in eye-patch.
7. Head turned 8° to the left; eye maintained 8° to the right by pinhole in eye-patch.
8. Head turned 8° to the right; eye maintained 8° to the left by pinhole in eye-patch.
9. Head held straight ahead; eye maintained 8° to the left by pinhole in eye-patch.
10. Head held straight ahead; eye maintained 8° to the right by pinhole in eye-patch.
11. Head held straight ahead; combined unit A & B positioned so that A is displacing to the right and B is displacing to the left.
12. Head held straight ahead; combined unit A & B positioned so that A is displacing to the left and B is displacing to the right.
13. Head turned 8° to the left; vision occluded by eye-patch; objects on left.
14. Head turned 8° to the right; vision occluded by eye-patch; objects on right.
15. Head turned 8° to the left; vision occluded by eye-patch; objects straight ahead.
16. Head turned 8° to the right; vision occluded by eye-patch; objects straight ahead.
17. Head turned 8° to the left; vision occluded by eye-patch; no objects (no reaching).
18. Head turned 8° to the right; vision occluded by eye-patch; no objects (no reaching).

The purpose of the various conditions can be summarized as follows: Conditions 1-12 were designed systematically to isolate variables believed to influence visual adaptation to laterally displacing prisms; head position, eye position, refraction (curvature, chromatic aberration,rarefaction and compression), and direction of displacement. The last six conditions (13-18) were designed to isolate possible effects of the reaching task and head turning from those factors producing or influencing visual adaptation. The eyes were occluded in each of these latter conditions, but the head turning and object-reaching tasks were varied.

The postexposure testing of the Ss took place at the conclusion of the ten-minute exposure. S was told to close his eyes, and was escorted back to the bite-bar position in the space localization unit. Six trials (2 random presentations of each of the 3 lights) were used to determine the postexposure score.

The results of the experiment are presented in Table 30. The data are reported in terms of the amount and direction of change in localization following an exposure condition (the postexposure localization mean subtracted from the pre-exposure mean).

The experimental conditions as designed involved a variety of factors which are believed to play some role in visual adaptation to rearrangement. Thus, for example, the classical visual factor is that of after-effect of wearing prisms. However, the wearing of prisms produces various effects in addition to the lateral displacement which is frequently discussed as though it were the only effect. Thus, additionally, the prisms provide refraction effects, i.e., rarefaction, curvature, etc.; positional effects are also produced: the head is turned to recenter the image to the degree of displacement, etc.

By attempting to evaluate systematically each of the factors separately, we hope to assign relative perceptual weights to each of the visual and non-visual components of the adaptational process. Thus, it is possible to assess those visual effects present in addition to prismatic displacement by utilizing mirror displacement. In the latter procedure, for example we produced all of the effects of the prism condition (displacement, change of head position, reaching, etc.) but eliminated all effects of refraction except displacement. Therefore, we reasoned, that if we subtracted the adaptational effects produced by wearing displacing mirrors from those produced by wearing displacing prisms we would have assessed the role of extra-displacement prismatic effects.

Table 30

Changes in Localization Following Exposure Conditions

Condition	Visual Experience	Eye Position	Object Position	Head Position	Amount & Direction of Localization Change
Lateral Displacement					
1	Refracting-L	S	S	L	3.59°R
2	Refracting-R	S	S	R	1.05°L
3	Reflecting-L	S	S	L	2.69°R
4	Reflecting-R	S	S	R	1.37°L
Eye Position					
5	Eye-Patch	S	L	L	.70°R
6	Eye-Patch	S	R	R	.31°R
7	Eye-Patch	R	S	L	.34°L
8	Eye-Patch	L	S	R	.03°L
9	Eye-Patch	L	L	S	.02°L
10	Eye-Patch	R	R	S	.56°R
Prismatic Effects (without displacement)					
11	Refracting-R & Reflecting-L	S	S	S	.27°L
12	Refracting-L & Reflecting-R	S	S	S	1.19°R
No Vision					
13	Eye Occluded	S	L	L	.99°R
14	Eye Occluded	S	R	R	.73°R
15	Eye Occluded	S	S	L	.74°R
16	Eye Occluded	S	S	R	.60°R
17	Eye Occluded	S	None	L	.31°R
18	Eye Occluded	S	None	R	.50°R

Note: Eye position is designated relative to the head; object and head position relative to S's body: S = straight ahead, R = right, L = left.

Specifically, Conditions 1 and 2 involve all prismatic effects; Conditions 3 and 4 are identical to 1 and 2 except that none of the extra-displacement effects are present. By subtracting the mean adaptation obtained in Conditions 3 and 4 (2.03°) from that of Conditions 1 and 2 (2.32°) we obtained .29° as an index of the extra-displacement effect of prism wearing (i.e., rarefaction, curvature, etc.).

We can obtain another indication of extra-displacement prismatic effects by measuring the adaptation resulting from the combination of displacing prisms and mirrors which displace the image to the same extent but in the compensating direction. Such a combination of prism and mirror with opposing effect leaves the true image of the target unchanged with regard to lateral displacement but produces the other distortions typical of prisms. The mean adaptation of Conditions 11 and 12 was .73°.

Although the two procedures (direct measure of extra-displacement prismatic effects of Conditions 11 and 12 versus the subtraction procedure of Conditions 1 through 4) yielded somewhat different effects, it might be pointed out that the displacement conditions (1-4) involved changed head position, whereas nondisplacement (Conditions 11-12) did not.

In order to evaluate the effect of displacement it is possible to subtract out the other variables. Thus, Condition 3 involves left mirror displacement; in Condition 15 there is no visual stimulation and hence no displacement. In all other respects the conditions are equivalent: eye position, head position, and direction of reaching. The radial difference between the mean adaptation in Condition 15 and that of Condition 3 gives 1.95°, an effect attributable to displacement alone. Similarly, if we take the radial difference between the mean of Condition 16 and that of Condition 4, we find the adaptation effect to displacement alone to be 2.10°.

The experiment produced other interesting results. Thus, we ignored the extra-displacement effects and averaged the two left-displacing conditions: (Condition 1 - prism with Condition 3 - mirror) and compared the mean degrees of adaptation (3.59° and 2.69°) with those obtained by right displacement (Conditions 2 and 4: 1.05° and 1.37°). The means show adaptive shifts for all conditions: left displacement produced right adaptation, and vice versa.

Moreover, the mean adaptation to left displacement was much larger than to right (3.14° versus 1.21°). At present we can only speculate that dextrality and the use of the right hand in the exposure and in the pointing tasks may have played some role in producing this difference.

Consistent with this view is the fact that in all the conditions in which vision was excluded (13 through 18) the direction of adaptation was to the right (from .31° to .99°). Furthermore, where exposure involved reaching (Conditions 13-16), positioning the head to the left yielded greater effects than when the head was kept to the right; where exposure did not involve reaching (Conditions 17-18) the opposite was true. Furthermore, the magnitude of adaptation diminished as the degree of reaching during exposure decreased. Thus, Conditions 13 and 14 required S to reach to right or left in the exposure task; Conditions 15 and 16 required less reaching (objects straight ahead); Conditions 17 and 18 required no reaching. The means of adaptation for the three pairs of conditions requiring from greatest to no reaching were: .86°, .67°, and .40° respectively. Consistent with this position is the finding that with eyes positioned straight ahead and with no visual effects interposed, (Conditions 5 and 6) adaptation was found consistently to the right; however positioning the head and reaching to the left produced a greater right adaptation than head position and reaching to the right.

Considering the data in another way, an interesting fact emerges. There were 14 conditions in which the eyes were positioned straight ahead, relative to the head. In six of them mirrors, prisms, or both were employed. For each pair of Conditions (1 and 2, 3 and 4, and 11 and 12) degree of right adaptation was greater than left. For all remaining eight conditions (5, 6, 13-18) in which the eyes were positioned straight ahead, all adaptation was to the right. Thus, when one controls for the added effects of visual rearrangement (mirrors, prisms) all conditions yielded right adaptation. In the four remaining conditions in which the eyes were positioned right or left (7-10) the greatest adaptation (Condition 10) was to the right and was achieved when the eyes and reaching were to the right. In the three remaining conditions although adaptation was to the left, the means were among the smallest obtained (overall M = .13°) and either eye position, reaching for target or both were to the left.

In summary, although we have not employed a statistical analysis, we believe our data have shown a great deal of consistency with previous positions, or internally. The results point to adaptational effects derivable from: (a) lateral displacement of the visual image, (b) extra-displacement effects of prismatic refraction, (c) eye and head position, (d) hand usage or hand preference. We cannot, as yet, entirely isolate all visual and nonvisual factors which play a role in the production of visual adaptation. However, we believe our data make a strong initial case for the necessity of studying factors such as limb, body, head, and eye position, muscle tension (EMG), lateral preference and usage, and visual rearrangement involving prism, mirror, and even differential sensory input into the various receptors (auditory, somesthetic, as well as visual). We believe it is only through thorough knowledge of the roles of sensory, motor, and cerebral mechanisms (dominance, alerting, etc.) that we will be able to understand more completely the mechanisms of perception.

Summary and Comment

The series of experiments described in this report was performed to investigate the roles of various types of informational feedback in producing visual adaptation to visual rearrangement and to various head, eye, and arm positions. A major goal was to test the validity of the theory of reafference. In all studies, informational feedback, exclusive of reafference was either equally effective in producing adaptation to rearrangement or somewhat superior.

1. A study in which Ss wore laterally-displacing prisms and were active or passive in wheelchair locomotion yielded significant, nondifferential positive adaptation.
2. Passive rotation in a chair of Ss wearing prisms was performed while feeding back information on egocentric localization. Significant positive adaptation occurred.
3. Disarrangement of eye-hand coordination employing a displacing mirror resulted in failure to replicate Held and Schlank's study favoring reafference.
4. Replication of our mirror-displacement study, utilizing Ss as their own controls again confirmed our finding that passive informational feedback is at least as effective, and possibly more effective in producing positive adaptation than is reafference.

5. We adapted the Wallach, et al. technique for producing prism adaptation in which an erect, stationary S observed his lower extremities. We obtained significant positive adaptation in the absence of reafference. Several Ss demonstrated 100% positive adaptation.

6. The criticism of the possibility of a "random walk" operating in our previous study stimulated us to its repetition. Confirmation of the proportion of positive adaptors was obtained refuting the "random walk" hypothesis. However, 100% adaptation was not obtained in this study.

7. A study was initiated in the attempt to determine whether positional or other nonvisual factors can function in the production of visual adaptation, and to isolate displacement from extra-displacement effects of prismatic refraction. The results clearly indicated visual adaptational effects derivable from: (a) lateral displacement of the visual image, (b) extra-displacement effects of prismatic refraction, (c) eye and head position, and (d) hand preference or direction of motion.

Comment. These studies, originating from prism-displacement research, have yielded a hard nucleus of data pointing to the influence of informational feedback derivable from body, head, and eye position upon visual perception. We now know that prismatic refraction can produce visual adaptation in the absence of active movement. We have thus shown that informational feedback is sufficient and most probably necessary, and that reafference is not necessary, and that its sufficiency may reflect the degree of informational feedback it provides. Further, we believe that prism wearing may provide visual adaptational effects through such nonvisual channels as differential input from neck-muscle receptors. Extrapolation of these results would seem to point to the value of studying the role of intermodal effects upon sensation and perception in all modalities.

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