Discriminative conditioning of prism adaptation*

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Two experiments were used to demonstrate that adaptation to 11-deg prism displacement can be conditioned to the stimuli associated with the goggles in which the prisms are housed. In Experiment 1 it was found that repeated alternation between a series of target-pointing responses while wearing prism goggles and a series of responses without prism goggles led to larger adaptive shift when S was tested with nondisplacing goggles than when tested without goggles. The results of Experiment 2 indicated that the adaptation revealed in the first experiment was primarily proprioceptive, rather than visual. Surprisingly, most Ss reported greater difficulty during the exposure period in overcoming the negative aftereffect than they did the prism-induced error.

Recently, it has been speculated that the well-known phenomenon of adaptation to a prism-displaced visual field is not a unique perceptual event, but merely another example of learning (e.g., Taub, 1968). One response to this suggestion is to look for characteristics that prism adaptation and the more traditional learning events have in common. For example, Goldberg, Taub, and Berman (1967) observed what appeared to be "prism aftereffect reminiscence." That is, adaptation was greater if measured a few minutes after prism exposure had ended than if tested immediately. Another "learning phenomenon" that has been noted with respect to prism adaptation is its conditionability. Kohler (1964) and, more recently, Pick, Hay, and Martin (1969) have shown that visual adaptation (and aftereffects) can occur to the prism-induced distortions of the visual field that are contingent upon head and eye movements. This finding demonstrates that different muscular sensations can become conditioned to different forms of visual adaptation. That *external* cues can also be conditioned to adaptation was seen in another study by Kohler (1964, p. 85) in which Ss wore spectacles, each eyepiece containing a prism in the top half and plain glass in the bottom half. Kohler found that the visual aftereffects were maximized by having S wear open spectacle frames with a wire in each eyepiece which divided the field into upper and lower halves.

In the current study an attempt was made to condition shift in felt body position, a form of prism adaptation first directly measured by Harris (e.g., 1963). Harris and others (e.g., Hay & Pick, 1966) have found that after a short period of time the prism-exposed body parts come to feel as if they are located where they were seen through the distorting medium. Thus, for example, if S viewed his hand through a prism which displaced it visually to the left, he would eventually come to feel as if it were to the left of its true position (with or without the prism).

The present attempt to condition prism adaptation entailed pairing sequentially (1) the prism-displaced visual field (and resulting corrective motor behavior) with the stimuli associated with the goggles in which the prisms were housed and (2) the normal visual field (and accompanying motor responses) with the stimuli associated with the absence of the goggles. The difference in stimulus situations was presumably in terms of the relative pressure and weight on the head and the size of the visual field. It was assumed that if conditioning occurred it would be revealed during the postexposure test as a larger shift in felt hand position on trials during which S wore prismless goggles than on trials when he wore no goggles, because the former type of measurement trial entailed the reinstitution of the stimuli present during adaptation.

EXPERIMENT 1

Subjects

The Ss were 40 undergraduate students at the University of Kansas. The group was made up of both volunteers and enrollees in an introductory psychology course, the latter having as one of its requirements participation in psychological research.

Apparatus and Procedure

The visual rearrangement consisted of an 11-deg leftward shift of the visual field, effected by means of welder's safety goggles which contained a 20-diopter wedge prism in each eyepiece. A representation of the testing apparatus has been published elsewhere (Welch & Rhoades, 1969). It consisted of a horizontal occluding board, elevated 12 in. above a table, with a biteboard attached to one end and a target at the opposite end. The target was a 7½ x 2/16 in. strip of luminous tape, running vertically the length of a weighted section of cardboard. The latter hung from a rubber cord directly above and parallel to the far side of the occluding board. A vertically sliding door, located approximately 7 in. from S's eyes, could be lowered to block his view of the target.

The testing session consisted of three periods—preexposure, exposure, and postexposure—the procedures for the first and third being identical. During the pre- and postexposure periods, measures were taken of the position in which S felt his unseen right index finger to be. In order to measure felt finger position, E first placed S's right arm on an inclined arm rest, located on the table directly beneath the occluding board. Then S's right index finger was guided into a finger holder at the far edge of the board and directly in line with the middle of S's body. At no time during this procedure was S able to see his arm, hand, or finger. With the lights extinguished, S bit into the dental-impression biteboard and operated a motor switch with his left hand, causing the luminous target to move laterally from a starting position on the far right of his visual field on half of the trials and on the far left during the remaining trials (in an "ABBA" order). The exact starting position on a given side was varied in a nonsystematic manner. The task was to stop the target when it appeared to be located directly above the unseen right index finger. It was permissible for S to move the target back and forth until he was satisfied with its position. When he had made his "final decision" S so indicated by tapping the table twice with his left index finger. He was then instructed to close his eyes, after which E lowered the sliding door, turned on the lights, and recorded S's accuracy by comparing the target's position with a metric ruler attached to the far edge of the occluding board. This procedure was repeated for a total of eight measures during the preexposure period and the same number in the postexposure period. On half of each set of eight trials, S wore clear glass goggles; on the remaining half he wore no goggles. For half of the Ss the clear glass goggles

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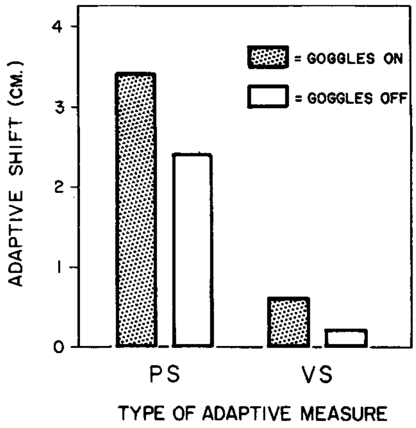

Fig. 1. Proprioceptive shift (Experiment 1) and visual shift (Experiment 2), measured with and without clear glass goggles.

were worn for the first two and last two of the eight trials; for the remaining Ss they were worn during the middle four trials. That is, 20 Ss received an ABBA order and 20 a BAAB order with regard to the "goggles-on" and "goggles-off" trials. For a given S the same order was used for the pre- and postexposure trials.

During the exposure period, S reached forward and under the occluding board with his right hand and curled his index finger around the edge of the board at the apparent position of the luminous target in the otherwise dark room. In order that he be able to see his finger at the terminus of each pointing response, S wore a luminous rubber finger. This pointing response was practiced by S during the preexposure period, before the measures of felt finger position had been taken. After the latter responses had occurred, S was informed that he would be asked next to point at the target in the same manner as he had practiced earlier. He was told that on some of the trials he would be wearing goggles that displaced his vision to the left. On the first trial he was to note the extent of his prism-induced error and then, on the subsequent trials, attempt to bring his finger up in the correct place. He was further informed that after the first 10 trials with the prism goggles he would be required to point 20 times with no goggles. As during the prism-goggles trials, he was to correct for any errors he might make.

The S pointed at the target a total of 300 times, repeatedly alternating between a series of 10 prism-goggles trials and a series of 20 no-goggles trials. The target's position was varied in a fixed irregular order among seven different locations, symmetrically arrayed around S's body midline (i.e., center and 6, 12, and 18 cm on either side of center). On the first no-goggles trial S would invariably miss the target to the *right*, which represented the negative aftereffect (NA) resulting from the visuomotor adaptation to the leftward prism displacement of the preceding 10 trials. Immediately after experiencing this error, S was told what it was and that he was to correct for it, just as he had the prism-induced error. During the exposure period S was never in any doubt as to whether or not he was wearing the prism goggles. Except for a short rest after each series of no-goggles trials, S gripped the biteboard throughout the period. He was requested to keep his eyes shut whenever his mouth was not on the biteboard.

The exposure period ended with a series of 20 no-goggles trials, after which S closed his eyes and removed his mouth from the biteboard, while E positioned his right arm and index finger in readiness for the postexposure measures of felt finger position. The clear glass goggles, which were weighted in such a way as to feel identical to the prism goggles, were then placed on S's head, and the postexposure trials began. After the last of these measures, S was asked the following question with reference to the exposure period: "Which was the more difficult for you to overcome on the first trial or two, the error caused by the prism goggles or the negative aftereffect?"

If S adapted proprioceptively to the leftward prism displacement, he should manifest this by a leftward prepost shift in the localization of his index finger. If this proprioceptive shift (PS) became associated with the stimuli emanating from the goggles, then it should be more in evidence during the goggles-on postexposure trials than on the goggles-off trials.

Results and Discussion

The left half of Fig. 1 reveals the main results of the first experiment. The PS was significantly different from zero for both goggles-on and goggles-off trials [$t(39) = 4.86$, $p < .005$ and $t(39) = 6.86$, $p < .005$, respectively]. A two-way analysis of variance, with repeated measures on one factor, was carried out, the two variables being type of trial (goggles-on/goggles-off) and order (ABBA/BAAB). The test revealed a significant effect for type of trial [$F(1,38) = 5.66$, $p < .05$] and nonsignificant effects for order [$F(1,38) = .21$, $p > .05$] and the interaction [$F(1,38) = 3.29$, $p > .05$]. Examination of Fig. 1 reveals that the difference in PS was in the direction indicative of conditioning.

A surprising finding was that 26 out of 39 Ss (one S failed to respond) reported that it was more difficult to overcome the NA than it was the prism-induced error. This difference in response frequencies was statistically significant ($\chi^2 = 4.22$, $p < .05$).

The results support the hypothesis that PS can become conditioned to the cluster of stimuli associated with the goggles worn during the prism-exposure trials. However, because felt finger position was measured by means of a visual pointer, it could be argued that the prepost shift in settings was due to a change in S's vision rather than in his proprioception. This is a valid criticism and was the basis of Experiment 2.

EXPERIMENT 2

Subjects

Forty Ss from the same population used in Experiment 1 participated.

Apparatus and Procedure

The optical rearrangement and the testing apparatus were identical to that used in the first experiment. The procedure was also the same, with one exception—the adaptive measure was of S's perception of "visual straight ahead." That is, during the pre- and postexposure periods S caused the luminous target to move (in the otherwise dark room) to a position which appeared to be directly in front of his nose. As in Experiment 1, four trials took place with weighted clear glass goggles and four with no goggles (20 Ss with an ABBA order and 20 with a BAAB order). The assumption was that if visual adaptation occurred during the exposure period, it would be seen as a leftward prepost shift in the setting of the target.

Results and Discussion

The results of Experiment 2 may be seen in the right half of Fig. 1. Two-tailed t tests indicated that the visual shift (VS) for the goggles-on trials was significantly greater than zero [$t(39) = 2.07$, $p < .05$], but that this was not true for the goggles-off trials [$t(39) = 1.00$, $p > .05$]. An analysis of variance of the type used in Experiment 1 produced Fs of .89 for type of trial, 1.01 for order, and 4.57 for the interaction. Only the interaction proved significant ($p < .05$).

The responses to the question regarding the relative difficulty of overcoming the prism-induced error and the NA revealed the same trend seen in Experiment 1. Twenty-seven Ss reported that the NA was the more difficult to correct, 11 said that the prism displacement was the more disruptive, and 2 Ss failed to respond. According to a chi-square test, the difference in frequencies was significant ($\chi^2 = 6.74$, $p < .01$).

The results of Experiment 2 suggest

that the shift in pointer settings manifested by Ss in the first experiment was primarily due to a recalibration of felt body position rather than a change in vision. However, the fact remains that some VS did apparently occur for the goggles-on trials in the second experiment. This finding suggests that a small portion of the adaptation seen during the goggles-on measurements of Experiment 1 was due to a change in vision. In fact, it is possible that in the first experiment the difference in total adaptive shift between the two types of measurement trial was due solely to a difference in VS.

GENERAL DISCUSSION

A comment is in order regarding the nearly significant interaction [$F(1,38) = 3.29$] found in Experiment 1 between order and type of trial. The nature of this interaction was that the difference between goggles-on and goggles-off adaptive shift was greater for the ABBA order than it was for the BAAB order. As indicated previously, "A" stands for goggles-on trials and "B" for goggles-off trials. A possible interpretation of this finding is that adaptation was not only conditioned to the presence of the goggles, but also to the *sequence* of goggles-on and goggles-off trials. This sequence was maintained for Ss in the ABBA group but was *reversed* for the BAAB group. The same interpretation applies for the results of Experiment 2 (in which the Order by Type of Trial interaction was statistically significant) because here, too, the difference in adaptation between goggles-on and goggles-off trials was greater for the ABBA group than for the BAAB group.

Shortly after Experiment 1 had been carried out, Uhlarik and Canon (1970) published a study of conditioned prism adaptation, using the presence of the goggles as the conditioned stimulus and NA as the adaptive measure. They found that a group tested on target-pointing accuracy while wearing nondisplacing goggles before and after prism exposure revealed significantly greater NA than did a group tested without goggles. A difference between the present experiment and that of Uhlarik and Canon is that the latter investigators used a separate group of Ss for the goggles-on and goggles-off pre- and postexposure measures, while in the present study a given S received both measures. Also of importance is the fact that in the present experiment a given S experienced the presence of the goggles in conjunction with the optical displacement as well as the absence of the goggles associated with a normal visual field. In other words, an attempt was made to elicit *discriminative* conditioning.

It is of theoretical interest that there remained any adaptation at all for Ss in Experiment 1, since of the 300 exposure trials, 200 were with normal vision (including the last 20). Thus, it appears that it is more difficult to "unlearn" prism adaptation than it is to become adapted in the first place. This conclusion agrees with the fact that most Ss reported more difficulty in eliminating NA than they did the prism-induced error. In fact, this phenomenon was obvious in the preliminary studies when it was found that if S was given an equal number of prism-goggles and no-goggles trials during the exposure period, PS was very large during the postexposure measures and equal in size for the two types of postexposure trial; hence, the decision to use twice as many no-goggles as prism-goggles trials during the exposure period.

As Uhlarik and Canon (1970) point out, the fact that prism adaptation can be conditioned to the presence of the goggles may have relevance for the common observation that NA is smaller than the reduction of error occurring during the exposure period. In other words, it is to be expected that a test for aftereffects without spectacle frames will lead to an underestimation of adaptation, because some of the stimuli associated with the adaptation are missing. Even if spectacle frames *are* worn, there may be a reduction in measured adaptation because of the absence of visual stimuli associated specifically with the prism (e.g., curvature of vertical contours, chromatic aberration, distortion of depth).

Finally, it must be pointed out that the present results do not represent a demonstration of *classical* conditioning. Pavlovian conditioning involves the repeated pairing of an originally "neutral" stimulus with a response-producing stimulus until the former comes to elicit a response identical or similar to that induced by the latter. Accordingly, the results of Kohler (1964) and Pick, Hay, and Martin (1969) qualify as examples of classical conditioning, in that different muscular movements eventually elicited different forms of adaptation. In the present experiment, adaptation could be measured with or without the conditioned stimulus (i.e., the goggles). Hence it is more appropriate to compare these findings to those which show that memory is most adequate if tested in an environment identical to that in which the subject matter was originally learned (e.g., Greenspoon & Renyard, 1957).

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