Readaptation and decay after prism viewing: An exploration of task variables from the viewpoint of the information discordance hypothesis

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Subsequent to prism adaptation, subjects may be readapted to their original visual-motor coordination using procedures similar to those occurring during adaptation. It has been argued that such procedures will be more effective than allowing for a decay of the aftereffect if normal visual-motor behavior is itself a state of adaptation. In the present study, two readaptation procedures were compared for their effectiveness to four decay and/or control conditions. Although all groups, except for one decay condition, showed significant reductions in prism aftereffects, only the two readaptation groups showed final aftereffects that were not significantly different from zero. It is argued that readaptation is distinguishable from decay and, further, that the necessary conditions for readaptation can be elucidated with reference to the information discordance hypothesis of prism adaptation. These arguments are primarily based on an extensive analysis in which discrepant information about the adapted arm's position is supplied by a nonvisual search task using the two arms.

Readaptation concerns the extent to which an observer who has adapted to prismatically displaced vision regains his or her normal, preexisting, visual-motor coordination. The premise of research on readaptation has been stated succinctly by Ebenholtz (1968): "The assumption that adaptation and perceptual development share many common processes carries the implication that the 'normal' preadaptation state is itself a state of adaptation" (p. 350). If this implication is correct, those procedures that were effective in producing the original prism adaptation ought to be equally effective in returning the subject to his or her original preadapted state under normal vision. These procedures should certainly be more effective than the simple passage of time, i.e., the simple decay of the aftereffects of prism viewing.

There are two studies that directly compare an experimental group readapting via the same procedures used for the original prism adaptation with a control group that should ostensibly only show simple decay of adaptation. Hamilton and Bossom (1964) produced changes in pointing at targets using Held's prism adaptation paradigm (Held & Gottlieb, 1958) in which subjects simply observe their own

continuous hand movements. Readaptation under normal vision was comparably successful for both an experimental group using the Held procedure and a decay group who sat in the dark for the same period of time. Hamilton and Bossom suggest that perhaps the success of the decay group indicates that innate mechanisms favor normal visuomotor coordination. Another suggestion was that the decay data may only indicate the effect of the greater practice for the original coordinations. Whatever the reason, the data do not support the implication that the normal state is a state of adaptation akin to that produced by the Held paradigm.¹

That the aftereffects of prism adaptation decay rather rapidly has been demonstrated in a number of studies using several different adaptation induction procedures (Choe & Welch, 1974; Foley & Maynes, 1969; Redding & Wallace, 1976). Very rarely, however, does the aftereffect, whether it is in target pointing, hand positioning, or eye positioning, become statistically nonsignificant in the 10-30-min decay period. This is so even when the decay period is longer than that for the original adaptation. There is even some evidence that subjects will show significant aftereffects of prism adaptation in target pointing and hand positioning 4 weeks after the original adaptation induction (Melamed & Sengbusch, Note 1). It is unclear whether such long-term effects indicate specific learned responses pertinent only to the adap-

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tation task procedures and/or environment or, as unlikely as it seems, generalized visual-motor behavior that persists outside of the laboratory. These effects do emphasize that "decay," as an experimental manipulation, must be looked at in a more precise fashion.

Ebenholtz (1968) has compared readaptation and decay after exposure to prismatically induced tilt rather than lateral displacement as in the Hamilton and Bossom study. The prism viewing situation had subjects walk back and forth along a corridor. Ebenholtz found that readaptation was superior to decay in restoring preadaptation tilt judgments. This was true for both 15° and 30° tilts. Readapting under normal vision, for a time period comparable to the original adaptation, reduced tilt aftereffects to the point that they were not significantly different from zero. Decays of aftereffects were sizable but significantly less than the readaptation change. Aftereffects were still 30% to 50% of their original magnitude. The decay procedure involved blindfolding the subjects and guiding them through the hallway.

In comparing Ebenholtz's findings to those of Hamilton and Bossom, it is difficult to draw any general conclusions. Consider the following list of procedural differences between the two studies. Ebenholtz's procedure comes first: (1) prism-induced tilt vs. lateral displacement; (2) hallway exposure vs. the Held-Gottlieb apparatus; (3) active movement during decay vs. sitting in the dark; (4) tilt (visual positioning) aftereffects vs. target pointing aftereffects. One way of furthering an understanding of prism readaptation would be to examine the implications of these procedural differences on the phenomenon. On the other hand, these procedural differences are numerous and, by and large, arbitrary. In order to systematically examine the comparability, or lack of it, between prism readaptation and decay of aftereffects, the present study attempts to distinguish these two phenomena while assuming a specific point of view on the nature of prism adaptation. Several different "decay" or control procedures are employed. They include the sitting-in-the-dark and the nonviewed-movement conditions of the two studies reviewed here. There are two experimental, or "readaptation," procedures. One is a straightforward repetition of the adaptation procedure under normal vision. The other is derived from a consideration of the nature of prism adaptation within the context of the particular induction paradigm used.

The approach to prism adaptation taken in the present research is that of the information discordance or discrepancy hypothesis (Wallach, 1968). Craske and Crawshaw (1978, p. 75) have described the basic assumptions concerning the coding of spatial information by this approach: "First let us assume that, in order to maintain the functional integrity of the organism, each of the sensory systems responsible for

spatial localization has modifiable parameters. Overall, the set of systems will operate to optimize performance of spatially organized behavior. Thus, it is expected that the brain will seek to minimize any between-system spatial discrepancy." This logic can be applied directly to the Held paradigm in which the subject merely observes his or her own continuous and self-initiated arm movement under prism viewing conditions. The information that is provided by the visual system and by the arm's own proprioceptive network for determining the spatial coordinates of the arm would be discrepant. The adjustments in target pointing behavior that a subject shows subsequent to prism viewing can then be ascribed to a recalibration in one or both of these systems to make their outputs congruent. Denoting exactly which of these systems are the ones undergoing adjustment, the nature of the actual adjustment, and the factors influencing these adjustments seems to be a primary aspect of present-day prism adaptation research (e.g., Craske & Crawshaw, 1978; Papp & Ebenholtz, 1976; Welch, Choe, & Heinrich, 1974).

Nevertheless, if adaptation occurs as the result of a cross-modality recalibration of spatial position information, it should be possible to produce readaptation using information other than that coming from the vision-proprioception discrepancy. Lackner (1977) was able to produce aftereffects in target pointing by exposing his subjects to a visual-proprioceptive conflict in arm position in which the proprioceptive information involved a lateral shift and the visual information was veridical. Lackner therefore demonstrated that displaced vision and veridical proprioceptive information are not necessary for target pointing adjustments. It should be possible under the information discordance hypothesis to demonstrate further that adjustments of the positioning of the arm can occur without any visual input. In the present experiment, this is demonstrated through the use of the readaptation paradigm. The procedure involves first adapting the subject using laterally displacing prisms. Readaptation then follows in which a blindfolded subject uses her hand that had been employed in the adaptation task to hunt for targets grasped by her other hand, the one that had not previously been used. Cohen (1967) has shown that very little, if any, transfer of adaptation occurs between the exposed and unexposed arm in the Held paradigm. Thus, the unexposed hand represents a veridical target for the subject in tracking the position of her adapted arm whose proprioceptive location has shifted due to the previous prism exposure task. Under the information discordance hypothesis, the degree of readaptation of the exposed arm that is obtained in this intramodality discordance condition should be similar to that produced by the condition in which the exposure task is repeated under normal vision. Both conditions should be superior to a number of

control conditions that do not provide similar discrepancies in spatial information about the exposed arm's position to the subject.

METHOD

Subjects

The subjects were 48 right-handed females recruited from the introductory psychology sections. They received course credit for participating. Only subjects who did not wear corrective glasses were selected.

Apparatus

The subjects were seated at a small wooden table with their heads securely positioned on a combination head- and chinrest. Throughout all experimental procedures, the subjects wore welder's goggles with Risley rotating prisms attached to the front surface. A wide cloth band was attached to the goggles and the headrest in order to further restrict head movement. The binocular field of view was approximately 45°. In front of the subject, on the table, was a rectangular wooden box, 49.5 × 77.5 cm, open on the side facing the subject. During the first exposure period, when the subject was to observe movements of her hand, it was placed in an aluminum holder that ran on an aluminum track on top of the box. Immediately behind the track was a wooden backboard that extended the entire width of the box. The subject's hand was visually coincident with the backboard. For the tests involved in measuring the negative aftereffects resulting from prism viewing of hand movement, a white tagboard was placed over the backboard. Three black lines, 5.08 cm apart, were centered on the tagboard. During these tests, the subject's hand was placed in a holder on an aluminum slide in the interior of the box. The slide was directly below the one on the surface of the box. Given the placement of the subject's head, her field of view, and her proximity to the position of the box on the table, no part of her arm or hand was visible in the test conditions. The location of the subject's judgment of a target line was determined by reading a value from a measuring stick that was attached to the interior slide and moved with it.

During the second exposure period, in which the readaptation procedures were applied, two of the groups used the following apparatus. The top of the wooden box was removed and replaced with a board containing seven 5.08-cm brass pegs that extended through the board. The pegs were mounted in rubber stoppers and could be wiggled freely from on top or from underneath. The middle peg was centered on the board, and the other six extended in a semi-circular arc away from the central peg. The pegs were 4° apart and subsumed a total visual angle of 24°.

Design and Procedure

A 6 by 2 mixed design was used. There were six readaptation and decay procedures (between subjects) and two measurements (within subjects) of the aftereffects in visual-motor coordination. There were six groups of eight subjects. All prism viewing was binocular, with the prisms oriented base left. All subjects went through a pretest of target pointing accuracy. This consisted of 10 practice trials for each of three line targets followed by five experimental trials for each of the targets. The order of judgments was randomized. The pretest was followed by a 10-min exposure condition for all subjects. This consisted of the subject viewing her own active arm movements while wearing 20-diopter prisms. The subject's hand movements were confined to the visual field and paced by the beat of a metronome. The exposure condition was immediately followed by a test of target pointing accuracy under normal vision. The structure of the test was the same as for the pretest. It consisted of five pointing trials for each of the three targets.

Immediately after the first postexposure test, the subjects were assigned to one of the six readaptation and decay conditions. These are described below. All of these manipulations involved normal vision and lasted 10 min. The final procedure was a second postexposure test of target pointing accuracy identical to the first.

Readaptation Procedures

(1) *Active group.* The subjects performed the same task as in the initial exposure period, i.e., they observed their own active arm movements but now under normal vision.

(2) *Proprioception 1 group.* The subjects were blindfolded and were instructed to search with their previously *exposed* (i.e., right) hand for the peg held underneath and wiggled by their previously unexposed hand. Their previously unexposed hand (the left) was placed randomly on the underneath side of one of the seven pegs by the experimenter. After the subject found the correct peg, another trial began. A record was maintained of the subject's success or failure on her first reaching attempt on each trial.

Decay (Control) Procedures

(1) *Dark group.* This is the absolute or prototypical decay condition. These subjects sat in the dark with their hands separately positioned on a pillow in their laps while their heads remained fixed. This group is similar to that used by Hamilton and Bossom (1964).

(2) *Light group.* The absolute decay of the Dark group was modified by having the room illuminated. The subjects still had their hands positioned on a pillow and their heads still fixed in the chinrest. Their field of view was the same as that for the Active group. This group served as a control for the effect of the viewed background on the amount of readaptation in the Active group.

(3) *Move group.* This condition served as a control for the effect of the movement aspect of the Active group procedure for adaptation. The subjects were blindfolded. Their task was to simply move their previously adapted hands back and forth through the same movement limits as during the initial exposure period. Although the adaptation procedure is different here, this control group is similar to that used by Ebenholtz (1968) as his decay group.

(4) *Proprioception 2 group.* The procedure is the same as Proprioception 1 except that the subjects searched with their previously *unexposed* (left) hands. Since the right hand only serves as a target, i.e., there is no need to guide its behavior and thus track its spatial position, it was not expected that this group would show as great a change in the level of adaptation as the Proprioception 1 group. The influence of this tracking requirement on the extent of adaptation in a similar task has been shown previously (Melamed, Halay, & Gildow, 1973). The Proprioception 2 group, from the point of view of the information discordance hypothesis, would not be required to integrate discrepant information about arm position.

RESULTS

Aftereffects were obtained twice for each group by subtracting either the first or second postexposure target-pointing performance from the preexposure results. These measures were averaged over the three targets. For purposes of analysis, these aftereffects were considered positive when in the direction of the prism base. These aftereffects are presented in Table 1 for each group. The significance of these aftereffects was evaluated using *t* tests for correlated measures (two-tailed).

As expected, all six groups showed significant aftereffects from the first exposure task. All were significant at the 1% level using the *t* test. The decrement in mean aftereffect from the first postexposure test to the second was nonsignificant for two of the decay groups (Move and Proprioceptive 2), significant for the other two (Dark, $p < .05$; Light, $p <$

Table 1
Mean Aftereffects in Degrees for Target Pointing

	Aftereffect Measure			
	First		Second	
	Mean	SD	Mean	SD
Readaptation Groups				
Active	5.14**	.47	2.10	.86
Proprioception 1	4.23**	.91	1.48	1.02
Decay Groups				
Dark	4.85**	1.17	3.63*	1.02
Light	6.02**	.98	3.58*	1.07
Move	3.40**	.83	2.53*	.94
Proprioception 2	4.35**	.64	3.09*	.72

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

.01), and significant for both readaptation conditions ($p < .01$). Finally, as can be seen in Table 1, only the decay groups retained significant aftereffects after the second exposure task, all at the 5% level. The Proprioception 1 and Active groups did not show significant aftereffects following their readaptation tasks.

In performing a mixed design analysis of variance, it was found that the Groups factor was not significant [$F(5,42) = .512$]. The Measures factor was significant [$F(1,42) = 79.41$, $p < .001$]. As would be expected from viewing Table 1, this finding reflected the general decrement in aftereffects that occurred following the second exposure period. The Groups by Measures interaction was also significant [$F(5,42) = 3.01$, $p < .05$]. This interaction was further evaluated using the Newman-Keuls procedure. Looking at each measurement period separately, none of the comparisons of the six experimental groups was significant in either case. The source of the interaction's significance seems to be in the comparisons evaluating the difference between the first and second measure of the aftereffects for the various groups. The findings using the Newman-Keuls procedure are, not unexpectedly, comparable to those described earlier in which the t test was used in evaluating these decrements between measurement periods.

DISCUSSION

The results of this study would seem to indicate that decay and readaptation procedures lead to distinguishable processes. Only the two readaptation groups showed readjustments to normal coordination to the extent that their aftereffects were no longer significant. Ebenholtz (1968) had a similar finding for his readaptation group. He further found that the time course of this readaptation was about the same as for the original adaptation. Decay, in his data, seemed to be a slower process. The same may be true of the decay process in the present data, at least for

the Dark and Light conditions. Both of these groups showed significant decrements in adaptation over the decay interval, but the aftereffects were still significant at that point.

The fact that not all of the decay conditions were effective in reducing the subject's level of adaptation, at least for target-pointing aftereffects, emphasizes the need to more closely examine and evaluate the processes of decay and adaptation-readaptation. The Move and Proprioception 2 conditions did not lead to significant reductions in the target-pointing aftereffects. These were the two decay procedures that involved some movement on the part of the subject. The data would seem to indicate that just generating such movement in the adapted arm, by itself, retards the ability of the original, preexposure visual-motor patterns to reassert themselves, i.e., for a decay or weakening of the postexposure aftereffects to take place. The Dark and Light groups performed no such movements and showed considerable decrements in aftereffects. On the other hand, the findings from the decay conditions indicate that the addition of visual exploration to the procedure (Light group) does not enhance the process of decay.

When the readaptation groups are examined, movement can clearly be seen as the major activity of these groups also. However, here it does not have a deleterious effect. The reason may be that this movement was not an isolated activity. It was used in performing a task with the adapted arm that involved tracking and controlling its movement. This was so whether the targets for this movement were visual (Active group) or the left hand (Proprioception 1 group). The fact that both groups showed strong readaptation may be used as support for the argument that the process of readaptation, as well as that of adaptation, involves the integration of discordant sensory information concerning the location of the arm. Furthermore, the equivalence of readaptation in the Active and Proprioception 1 conditions, the latter not involving the use of visual information, may be taken as an argument for a proprioceptive locus of the adaptive adjustments, at least as measured by errors in target pointing. In the Active group, there was a discrepancy between the location of the arm indicated by the visual localizing system (eye-head) and the hand-head proprioceptive positioning system. Both sets of information had to be synthesized in order to perform the pointing task. For the Proprioception 1 group, the task involved controlling the movement of the previously adapted arm (right) to make it coincident with a target provided by the left hand. Discordant information about the location of the right arm was provided by the conflict between the feedback from its own proprioceptive network at the end of each movement excursion as to its location and the position of the intended target for its move-

ment, the left hand. It is probably not important that the target is the left hand, only that it provides information for evaluating the position of the right hand in guiding that hand's movement.

For the information discordance hypothesis to apply to the findings of the present experiment, it is also necessary to show that such discrepant information was not available, or at least not likely to be used by the subjects in the Proprioception 2 group. It would seem fair to assume that the subjects in the Proprioception 2 group viewed their main task as guiding the left arm to a location defined by the position of the right arm. The right arm is passive in the Proprioception 2 condition. There is no need to track its movement when it is placed under a peg. There is no need to even evaluate the right hand's position when errors in reaching with the left hand take place. This data is very reminiscent of the superiority of active over passive movement that occurs when a homogeneous exposure background is used in the Held paradigm. This superiority disappears (Melamed, Halay, & Gildown, 1973) when visual markers are provided to the passive movement subjects to aid them in tracking their own movements and, perhaps, to provide the means to do so by indicating the difference between the viewed and proprioceptive location of the moving hand.

Fortunately, there is some data available from the readaptation procedures of the two proprioception groups that supports the argument that the subjects' approach to the task and their use of and integration of available information about arm position were quite different in the two procedures. These data are provided in Table 2. It shows the mean number of correct reaches for the target in each of the six blocks of trials over the 10-min readaptation periods of Groups Proprioception 1 and Proprioception 2. It was possible for the subject to reach correctly seven times in each block of trials. It should be recalled that the difference between the groups is in whether the subjects searched with the hand previously exposed to the prismatic displacement (right hand) for the previously unexposed one (left hand), as in Proprioception 1, or vice versa.

Although the overall number of correct trials was not significantly different between the two groups [$F(1,14) = .91$], the Blocks [$F(5,70) = 6.14$, $p < .001$] and Groups by Blocks [$F(5,70) = 3.43$, $p < .01$] terms of the analysis of variance were significant. From Table 2, it can be seen that the subjects in the Proprioception 1 group show a typical learning curve in their reaching performance. They start out very poorly in reaching accuracy, averaging less than one correct trial in the first block. They asymptote by Block 4 at approximately 4.3 correct trials. The task is somewhat more difficult than anticipated. The Proprioception 2 group starts out much more

Table 2
Mean Number of Correct Reaching to Target Trials (Per Block)

Group	Blocks					
	1	2	3	4	5	6
Proprioception 1	.75	1.38	3.38	4.38	4.25	4.38
Proprioception 2	2.00	3.12	3.00	3.00	2.75	3.12

accurate on the initial trial block but still performing rather poorly, averaging 2.00 correct trials. Moreover, this performance stays constant at about 3.00 correct trials over all the remaining blocks of trials. This group does not show any real learning of this task. A Newman-Keuls analysis of the Groups by Blocks interaction supports this interpretation. None of the pairwise comparisons between block means were significant for the Proprioception 2 group. On the other hand, for the Proprioception 1 group, Blocks 4, 5, and 6 were all significantly different at the 1% level from Blocks 1 and 2. Block 3 is also significantly different from Block 1 ($p < .01$) and Block 2 ($p < .05$). All other comparisons are nonsignificant. These data certainly seem to show a rapid learning of the reaching task with a rather low ceiling on performance.

The analysis of the data in Table 2 must, of course, be viewed cautiously. These data do not come from a proper experimental design. Such a design would contain, as a minimum, control groups which had *not* had the prior adaptation manipulation. It would be intriguing to also have two readaptation groups parallel to those already used but in which the left hand is adapted during the exposure period. The problem is that it can be argued that the left hand is simply poorer at searching for the right hand than vice versa. This does not seem a particularly compelling hypothesis, however. The Proprioception 2 group did not have significantly fewer correct trials overall compared to Proprioception 1. They were simply distributed differently. Further, it would seem unlikely that such skill differences between the hands could account for the lack of learning in the Proprioception 2 condition. The data would seem to most directly argue that there is little or no integration of information from the two arms about the spatial position of the right hand in the Proprioception 2 procedure. It seems remarkable how independently the two head-hand systems can function under appropriate circumstances.

REFERENCE NOTE

1. Melamed, L. E., & Sengbusch, L. *Reliability and individual differences factors in prism adaptation*. Paper presented at the meeting of the Psychonomic Society, San Antonio, Texas, November 1978.

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NOTE

1. There is an apparent error in Hamilton and Bossom's data analysis that mitigates against the acceptance of their finding of no difference in the degree of readaptation between their experimental and control (decay) groups. A *t* test for independent groups was used rather than the appropriate one for correlated samples. Although this increases the *dfs* for evaluating *t*, it also increases the variability estimate over what it would be if based on difference scores. Not knowing the relative size of these two conflicting bias factors makes it difficult to accept at face value Hamilton and Bossom's failure to find a statistically significant difference between their groups.

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