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ADAPTING TO VARIABLE PRISMATIC DISPLACEMENT[1]

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SUMMARY

In each of two studies subjects were exposed to a continuously changing prismatic displacement with a mean value of 19 prism diopters ("variable displacement") and to a fixed 19-diopter displacement ("fixed displacement"). In Experiment 1, we found significant adaptation (post-pre shifts in hand-eye coordination) for fixed, but not for variable, displacement. Experiment 2 demonstrated that adaptation can be obtained for variable displacement, but that it is very fragile and will be lost if the measures of adaptation are preceded by even a very brief exposure of the hand to normal or near-normal vision. Contrary to the results of some previous studies, we did not observe an increase in within-S dispersion of target-pointing responses as a result of exposure to variable displacement.

INTRODUCTION

Human observers who are allowed to view their actively moving hands through an optical medium that displaces, inverts, right-left reverses, or otherwise rearranges the visual field reveal significant adaptive changes in hand-eye coordination (Welch, 1978). For example, the initial errors made when one looks through a wedge prism and attempts to touch a target are typically corrected in a matter of minutes. Depending on the nature of the exposure conditions, this prism-adaptive shift in hand-eye coordination can be based on changes in (1) the felt position of the limb (e.g., Harris, 1965); (2) visual localization (e.g., Craske, 1967); or (3) the algebraic sum of both of these events (e.g., Wilkinson, 1971).

An alternative to prismatic displacement of constant strength (which may be referred to as "fixed displacement") is one that varies continuously in both magnitude and direction ("variable displacement"). It has been shown by Cohen and Held (1960) that active exposure to a variable displacement in the lateral dimension with a mean value of zero fails to produce an adaptive shift in the *average* location of the subject's repeated target-pointing attempts, although it does appear to increase the *variability* of these responses around the mean. The latter observation has been interpreted as a degradation in the precision of hand-eye coordination.

The absence of adaptation to this form of variable displacement should not come as a surprise, since, over the course of the prism exposure period, there is no net prismatic displacement to which one can adapt. What remains to be determined, however, is whether it is possible to adapt to a situation of variable displacement in which the mean value is significantly different from zero, since in this case it is at least plausible for such adaptation to occur. The aim of the present

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investigation was to answer this question and, in addition, to compare the magnitude of such adaptation with that produced by comparable fixed prismatic displacement.

METHOD

General Design

Two experiments were carried out. In both, subjects were used as their own control under conditions of fixed and variable prism exposure to the same average displacement (19 prism diopters). This comparison is seen in figure 1. Experiment 1 also included the between-group factor of direction (up vs. down) of the optical displacement of the hand that was present during exposure. Prism adaptation was indexed by the difference between pre- and postexposure target-pointing accuracy without visual feedback (visual open-loop).[2] Also obtained were post-pre differences in the within-S variability (standard deviation) of target-pointing over the 10 pre- and 10 postexposure trials. Finally, potential intermanual transfer of the prism-adaptive shifts in target-pointing was examined by testing both exposed and nonexposed hands.

General Procedure and Apparatus

At the outset of the testing period, subjects sat at a table with faces pressed into the frame of a pair of prismless (normal-vision) goggles built into a box. Looking into this box, they viewed the reflection of a back-illuminated 1- by 1-in. cross, the apparent position of which was straight ahead at approximately eye level and at a distance of 48 cm, nearly identical to that of a vertically positioned 12- by 12-in. touch pad. For the preexposure (and later the postexposure) measures of target-pointing accuracy, subjects pointed alternately with the right and left index fingers (10 responses each), attempting to contact the touch pad at a place coincident with the apparent center of the cross. The inter-response interval was approximately 3 sec. The mirror blocked the view of the pointing hand, thereby precluding error-corrective visual feedback. When subjects touched the pad, the X and Y coordinates of the finger's position were immediately signaled and written to a floppy disk, using a program supported by an Apple II Plus computer.

During the prism-exposure period, the prismless goggles were replaced by binocular prisms (variable or fixed) and the mirror was moved out of the way, allowing subjects to see the touch pad as well as the hand when it was brought into view. In addition, a hand-movement guide consisting of a vertical rod was situated parallel to and approximately 9 cm away from the surface of the pad.

The exposure period consisted of a series of 55-sec cycles. During the first half of each cycle, subjects, who were looking through the (upward- or downward-displacing) prisms, actively moved the preferred hand up and down along the rod, fixating the limb at all times. They grasped the rod with the thumb hooked around the rod and the palm of the hand facing them. Hand

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[2]An attempt was also made to obtain measures of prism-adaptive shifts in felt-limb position. During the pre- and postexposure periods, subjects (with eyes shut) were to try to place the right and left index finger (alternately) at a position on the touch pad that they felt to be directly in a horizontal line with an imaginary point in the center of the bridge of their nose. Unfortunately, many subjects reported that they approached this task as if it were merely another form of target-pointing. Furthermore, their responses were erratic and the data were difficult to interpret. For these reasons, the results from these measures have been omitted from this report.

movements were made to the beat of a 1-Hz electronic metronome; the limb was moved up on the first beat, down on the next beat, and so forth, for exactly 27.5 sec. Then for the next 27.5 sec the subjects rested the hand on the table and fixated the cross while looking through the goggles, which were now set to produce displacement in the opposite direction. This was followed by 27.5 sec of observed hand movement, with the direction of prismatic displacement returned to its original state. Subjects alternated between these two displacements for a total of nineteen 55-sec cycles (17:25 min). Finally, postexposure measures of target-pointing accuracy were obtained in the same manner as the preexposure measures.

The conditions of fixed downward and fixed upward displacement were achieved by means of paired base-up and base-down wedge prisms, respectively. The prisms were attached to a sliding panel that moved them to a position directly in front of the goggle eyepieces. Variable displacement in the vertical dimension was produced by a pair of binocular, motor-driven Risley prisms which rotated in opposite directions; the net result was a binocular optical displacement that continuously changed in the vertical dimension over a range of ±30 diopters (±17.1°).

Measures of potential prism-adaptive shifts in target-pointing accuracy in the vertical dimension were obtained by subtracting (for each hand separately) the mean of the 10 preexposure responses from the mean of the 10 postexposure responses. Potential prism-induced changes in within-S variability of target pointing were determined by subtracting the standard deviation of a given subject's 10 preexposure measures (for a particular hand) from the standard deviation of the corresponding 10 postexposure measures.

EXPERIMENT 1

Design

Twelve subjects (8 males and 4 females, ages 19-33) were randomly divided into two 6-subject groups. For one group the visual field was displaced upward during that half of each cycle in which the subject viewed the actively moving hand; for the other, the field was displaced downward. Subjects were tested individually in two conditions–variable displacement and fixed displacement–occurring 48 hr apart. The order of the two conditions was counterbalanced across subjects.

Procedure

Following the preexposure measures of open-loop target pointing, the mirror was removed and subjects looked through prismless (i.e., nondisplacing) goggles while undergoing the nineteen 55-sec cycles. On each cycle the hand was viewed for 27.5 sec, followed by 27.5 sec of viewing the target cross while the hand was resting on the table out of view. The purpose of this long period of normal vision was to establish an accurate and reliable baseline measure of each subject's perception of the hand's location under nondistorted visual circumstances before introducing the prismatic displacement. After a short rest break, subjects repeated the procedure, but this time they viewed the moving hand through prisms that were set either for fixed or for variable displacement. In order to reduce the possibility of significant loss of adaptation through spontaneous decay, the postexposure measures were obtained immediately after the subjects had viewed the prismatically displaced hand, which necessitated terminating the last cycle after the first 27.5 sec. It is important to note that because of this procedural decision the last view of the hand for the fixed displacement condition was one of 19 diopters' displacement, while for the variable-displacement condition it entailed little or no displacement (see fig. 1).

Results

As shown in figure 2, prism-adaptive shifts in target-pointing accuracy for the exposed hand were obtained in the fixed, but not in the variable, displacement condition for both the upward and downward displacement groups. The finding of adaptive post-pre shifts for both directions of displacement confirms that these changes represent adaptation to the prisms *per se,* rather than some form of "drift" of pointing accuracy over time due to fatigue or other factors unrelated to the prismatic displacement. Analysis of variance revealed main effects for Direction (up/down), $\underline{F}$ (1,4) = 14.49, $\underline{p} = 0.22$, and Displacement (variable/fixed), $\underline{F}$ (1,4) = 30.01, $\underline{p} < 0.01$, and for the Direction/Displacement interaction, $\underline{F}$ (1,4) = 82.14, $\underline{p} < 0.001$. Figure 2 indicates that the difference between the variable and fixed displacement conditions was greater for the upward displacement group. There was no main effect for order, nor was this factor involved in any interactions. Adaptation for the nonexposed hand (due to intermanual transfer) was obtained only for the fixed/upward displacement condition.

No statistically significant post-pre shifts in the dispersion (standard deviations) of target pointing were obtained for either hand in any condition.

Finally, for none of the conditions was there evidence of any decay of adaptation over the 10 postexposure trials for either hand.

Discussion

Since adaptation occurred for fixed but not variable displacement, the answer to the original experimental question would seem to be that human observers are *not* capable of adapting to nonzero variable displacement, at least with exposure periods of the length used here. There is, however, an alternative possibility, based on the fact that for subjects in the variable-displacement condition, the last experience during the prism exposure period was of normal or near-normal vision (fig. 1). It may be suggested that the adaptation produced in this experiment (or perhaps specifically in the variable-displacement condition) is quite *fragile* and therefore easily destroyed by subsequent exposure to normal vision. If so, then one could suppose that adaptation was actually produced in both conditions, but eliminated for the variable-displacement condition because of the "unlearning" that occurred at the very end of the exposure period. Experiment 2 attempted to examine this possibility by asking the following question: Does the difference in adaptation in favor of fixed displacement that was obtained in Experiment 1 remain when the exposure period for the variable-displacement condition is caused to end on maximum displacement, rather than on no displacement?

EXPERIMENT 2

Design

Six subjects (2 males and 4 females, ages 21-39) were used as their own control in conditions of variable and fixed displacement in the upward direction only. The two conditions were separated by 48 hr and their order of occurrence counterbalanced across subjects.

Procedure

During the prism-exposure period, subjects viewed the preferred hand in the same manner as in Experiment 1, with the addition of one extra half-cycle. The latter ended after only 13.75 sec, which meant that the prismatic displacement for the variable condition was at its maximum of 30 diopters while the displacement for the fixed condition remained at its constant level of 19 diopters (see fig. 1).

Pre- and postexposure measures of target-pointing accuracy for both hands were taken in the same manner as in Experiment 1.

Results

As may be seen in figure 3, prism-adaptive shifts in target-pointing accuracy were found for both variable and fixed-displacement conditions and both exposed and nonexposed hands. All of the post-pre shifts were significantly different from zero, but there were no main effects for the factors of Hand (exposed/non-exposed) or Displacement (variable/fixed), nor any interactions. Once again, no prism-induced changes in target-pointing precision (within-S standard deviations) or postexposure decay of adaptation were observed.

Discussion

The results of Experiment 2 are consistent with the "fragility hypothesis," since when the most recent visual experience in the variable-displacement condition was of maximum displacement, adaptation was substantial and, indeed, as great as that produced by fixed displacement. An interesting secondary finding was the large amount (i.e., 100%) of intermanual transfer produced.

CONCLUSIONS

The present study has demonstrated that human subjects are capable of adapting their hand-eye coordination to nonzero variable displacement, although this adaptation is quite easily destroyed. It is possible, of course, that this fragility is unique to the current situation in which the prism-exposure task did not involve visual error-corrective feedback and exposure periods were repeatedly interrupted by rest periods. Furthermore, the present design does not allow us to exclude the possibility that the adaptation produced in the fixed-displacement condition was also fragile and would therefore have been quickly eliminated by exposure to normal vision.

A surprisingly large amount of adaptation was observed for the nonexposed hand, especially in Experiment 2. This may have been due to the use of alternating exposure and rest periods, since "distribution of practice" has been demonstrated to facilitate intermanual transfer of prism adaptation (e.g., Cohen, 1973). Such intermanual transfer has frequently been used as evidence that prism-adaptive changes in *vision* have occurred. Evidence against this interpretation of the present observations, however, comes from studies (e.g., Uhlarik and Canon, 1971) showing that prism exposure not involving target-pointing, as in this experiment, is generally ineffective in producing this kind of adaptation. An alternative interpretation of intermanual transfer of prism adaptation is that it represents a central change in motor programming that is usable, at least to some extent, by the nonexposed hand.

Contrary to the results of Cohen and Held (1960), neither of the present experiments revealed an increase in the dispersion of target pointing as a result of exposure to variable displacement. Two explanations for this failure to replicate may be proposed. First, it is possible that the presence of only one target for the pre- and postexposure trials (in contrast to the four used by Cohen and Held, 1960) was conducive to a "stereotyping" of target-pointing responses. Such a potential constraint on trial-to-trial variability would be likely to counteract any disruptive effects that variable displacement might have on the within-subject dispersion of responses. Second, the present exposure period was relatively brief in comparison to that used in the Cohen-Held experiment. Indeed, in the latter, no increase in dispersion was obtained until after 30 min of variable displacement. In the present experiment, actual exposure to the hand (excluding the 27.5-sec "rest" periods) amounted to only a little over 8 min.

It is of interest to speculate why variable prismatic displacement should produce adaptation that is so easily destroyed (assuming that future research supports this conclusion). One possibility is that exposure to variable displacement causes the adaptive system to be quite labile and therefore easily changed, even by very brief exposures to new visual displacements or to normal vision. This interpretation fits with the finding by Cohen and Held (1960) of degraded hand-eye precision after exposure to variable displacement, but is weakened by the present failure to replicate the Cohen-Held observation.

A second possibility is that subjects exposed to variable-displacement experience only "visual capture," a nearly instantaneous shift in felt-limb position when viewing the prismatically displaced hand (Welch and Warren, 1980). Since visual capture is extremely fragile, it will be destroyed by even a brief exposure to normal vision and will also rapidly decay when view of the hand is precluded. The quick decay of visual capture, however, contrasts with the absence of postexposure decay in either of the present experiments, rendering this interpretation questionable.

The most likely explanation of the present results is that when human observers are actively exposed to a systematically changing prismatic displacement, they acquire the ability to adapt (or readapt) nearly instantaneously, as required. Such presumptive adaptive flexibility would represent a clear advance over the situation with fixed displacement, since the latter involves relatively slow acquisition of adaptation and the presence of substantial aftereffects upon return to normal vision. In short, it is possible that prolonged exposure to variable displacement provides the observer with the ability to shift from one set of visuomotor relationships to another with a minimum of disruption. An experiment to evaluate this interpretation is currently being implemented.

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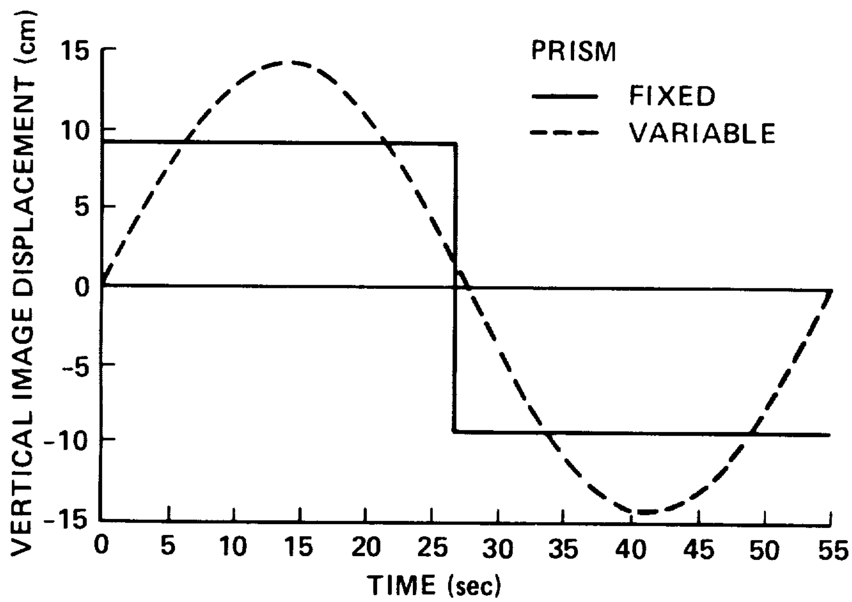

Figure 1.– Prismatic exposure conditions: Fixed and variable prism displacements.

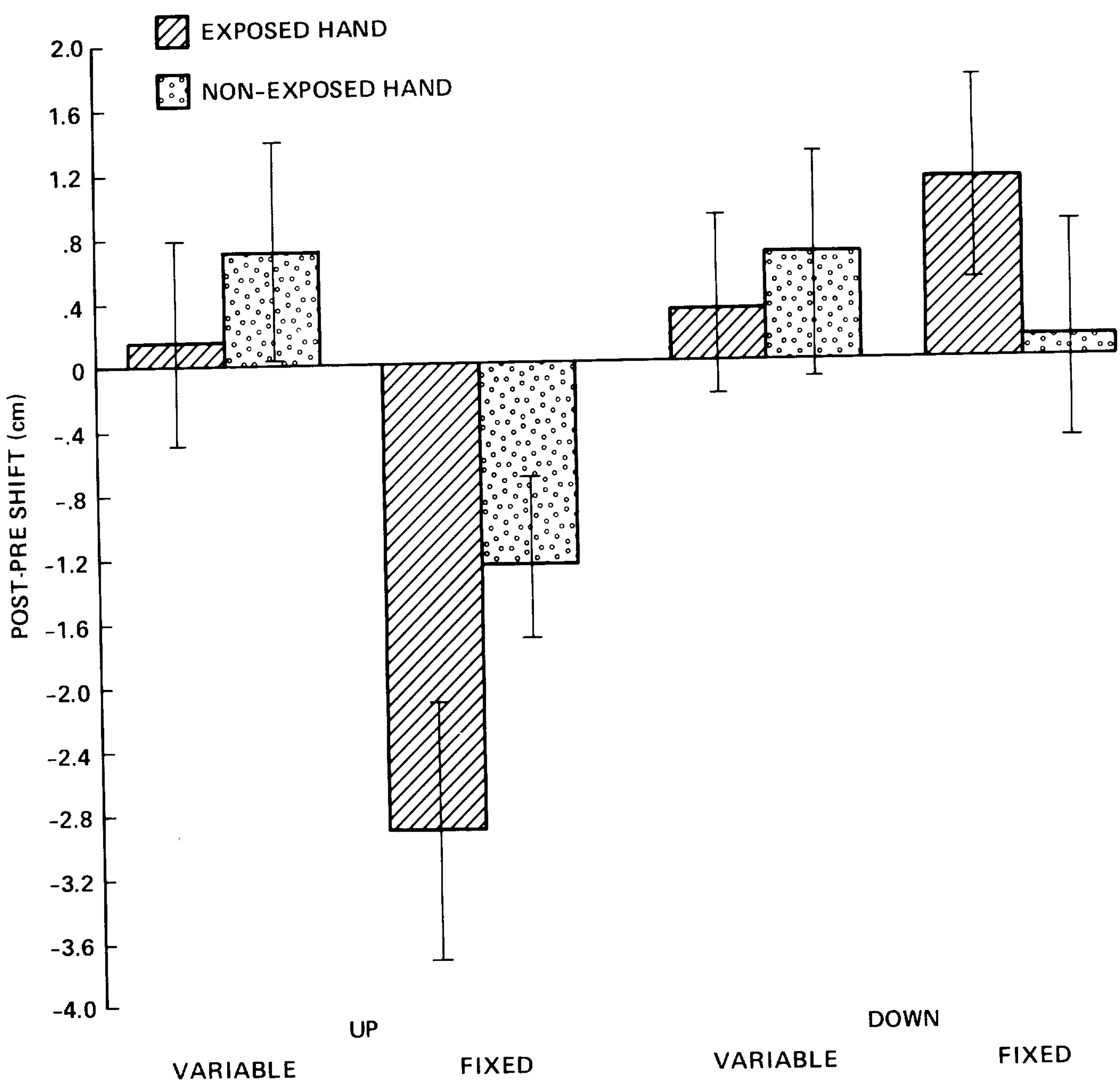

Figure 2.– Experiment 1: Post-pre shifts (cm) in target-pointing accuracy.

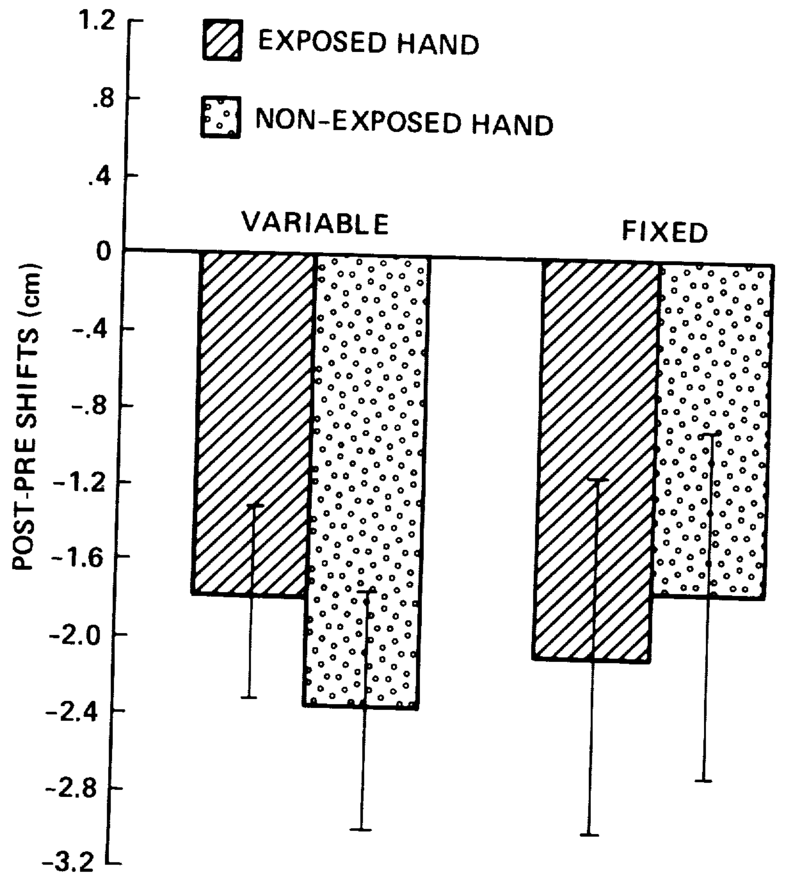

Figure 3.– Experiment 2: Post-pre shifts (cm) in target-pointing accuracy.