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Simultaneous visuomotor adaptation to optical tilt and displacement

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Change in visuomotor direction and orientation was measured following simultaneous exposure to optical displacement and tilt. Adaptation to both transforms simultaneously was not different from adaptation to each transform separately. These results are consistent with previous work involving purely visual change, and suggest that the two kinds of adaptation involve independent processes for locus-specific and relational analysis.

Implicit in theories of perceptual adaptation (e.g., Harris, 1965; Held, 1961; Rock, 1966) is the idea of a single, limited-capacity mechanism mediating perceptual adaptation to both optical tilt and optical displacement. A test of this hypothesis is possible by simultaneously exposing subjects to lateral displacement and rotational tilt of the visual field. The rationale of this procedure is that the combination of tilt and displacement produces a more difficult problem of compensation if adaptation to the two transforms involves the same mechanism. Hence, tilt and displacement adaptation should be reduced compared to the level attained for a single transform. The contrary conclusion of perceptual independence based on performance parity (Garner & Morton, 1969) assumes that each of the two tasks separately requires maximal capacity. Since adaptation to either tilt or displacement is rarely, if ever, complete (i.e., usually asymptotic at less than 100%), this is a reasonable assumption. Thus, when tilt and displacement are combined, a failure to show a decrement in adaptation is evidence that the two tasks do not involve overlapping capacity.

Previous work (Redding, 1973a) failed to find evidence of interference predicted by the single-channel hypothesis when the exposure and test conditions emphasized visual adaptation. Adaptation to both transforms simultaneously was not different from adaptation to each transform separately. The conclusion of independent mechanisms for visual adaptation to tilt and displacement was further supported by parametric comparisons of the two kinds of adaptation (Redding, 1973b). Tilt adaptation is rapid and asymptotes at a relatively low level of compensation, while displacement adaptation is much slower but asymptotes at a higher level of compensation. Similarly, decay of displacement adaptation is slower then decay of tilt adaptation. Finally, comparison of performance of subjects exposed to both transforms, but on separate occasions, revealed an absence of a correlation between individual performance under the two transforms.

The test and exposure conditions employed in these earlier experiments emphasized purely visual change, i.e., change in the phenomenal appearance of the visual world. During exposure, subjects walked freely in hallways, but were prevented from viewing any part of their bodies by a cloak which reached from neck to knee and were instructed not to touch walls. Tests required visual judgments of egocentric (relative to the head) orientation and direction. Thus, it is unlikely that any proprioceptive change, such as in felt position of the hand (Harris, 1963), or specific visuomotor compensation, such as eye-hand coordination (Mikaelian, 1967), occurred, and conclusions must be restricted to visual adaptation. Furthermore, there is reason to believe that the conclusion of independent mechanisms cannot be generalized to other test and exposure conditions, viz, conditions emphasizing visuomotor change.

Held (1970) has suggested that spatially distributed visual information is processed in two distinctively different ways, depending upon stimulus and task characteristics. A locus-specific mode of analysis retains information about specific retinal locus, and is invoked by the absence of extended contours in the stimulus or by the requirement of an orienting motor response, such as pointing at specific loci. The second kind of processing is involved in form perception where only relational information among contours is required or where a nonorienting identification response is necessary. Held has employed this distinction to explain a variety of behavioral data, including differential rates of adaptation to localization and form distortions (Held, 1968), and a

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similar division of the visual system has been proposed to account for dissociation of orienting response and shape discrimination in tectal and cortical lesioned animals (Ingle, 1969; Schneider, 1967, 1969; Trevarthen, 1969). Redding (1973a) suggested that the differences found in visual adaptation might be due to the involvement of locus-specific analysis in displacement adaptation while relational analysis is involved in tilt adaptation.

The experiment reported here was designed to maximize the possibility that the locus-specific mode of analysis was involved in both tilt and displacement adaptation. Eye-hand coordination tasks were required during both exposure and test, and targets during test were discrete dots, notably lacking contours. Under these conditions, the locus-specific system should be invoked for both kinds of distortions, and interference should arise with the simultaneous combination of tilt and displacement.

METHOD

Procedure

A Held-Gottlieb (1958) type of apparatus was used in the experiment. During exposure, subjects traced the outline of a square, 3.0 cm on a side, with their index fingers, moving in a clockwise direction. The square was located at eye level on a surface perpendicular to the line of regard at a distance of approximately 53.34 cm. The test stimulus was a vertical row of three dots, approximately 2.0 mm in diam and separated by 1.5 cm. The total vertical extent of the test stimulus was, therefore, 3.0 cm. The dots were physically located above the subject in a plane parallel to the line of regard, and were viewed in a mirror such that their apparent location was in the same plane as the exposure square. The subjects judged the apparent location of each dot by making marks with a pencil, first for the top dot, then the middle dot, and ending with the bottom dot. To tacilitate scoring, a straight line was fit, by eye, to the three marks produced by the subject. Orientation was measured by taking the angular deviation of the fitted line from objective vertical. Location was assessed by measuring the lateral deviation of the fitted line from objective straight ahead. The point on the fitted line nearest the middle mark was taken as the reference point in assessing location. Level of adaptation (LA) was defined as the difference between the mean of nine pretests and the score at each subsequent posttest. All tests were made without prisms, and the head was held stationary by a face mask mounted on the front of the viewing box. Exposure was monocular, right eye only, only right-handed subjects were used, and only clockwise tilt and rightward displacement were used.

Design

Initially, three groups of 16 subjects each were run. The three groups differed only in the kind of transform received: tilt and displacement, tilt only, and displacement only. Tilt was produced by pairs of dove prisms, mounted in tandem, and displacement by wedge prisms. In the combination condition, the wedge prism was mounted between the subject's eye and the dove prisms. Alternate assignment of subjects to groups was maintained. Tests were conducted at 3.0-min intervals, five tests in all, for a total exposure time of 15 min.

Subsequently, two additional groups of 16 subjects each were run, one group receiving only tilt and the other both tilt and displacement. These groups were necessary to control for a slight tilting effect produced by the wedge prism when combined with the dove prisms. This tilt effect is small (approximately 2° clockwise in the present case) and is due to imperfect alignment of optical axes of the two kinds of prisms. The dove prisms alone produce a slight displacement effect (approximately 0.5 D), and when combined with the wedge prism the result is misalignment of the optical axes. Consequently, light from the target does not pass through the center of the wedge prism and is subject to the shearing effect of the wedge prism. Since there was no a priori way to know whether this kind of tilt effect would combine, perceptually, with the tilt produced by the dove prisms, in the initial calibration the tilt-only and the tilt-and-displacement conditions were empirically equated in terms of tilt, the result being that the dove prisms were set at 20° and approximately 18° for the two conditions, respectively. To control for any effect of this difference in the dove prisms, the wedge prism was subsequently interchanged and the two additional groups were run with the tilt-only group receiving 18° and the tilt-and-displacement group receiving 20°. The wedge prisms used were of a constant 20-D value.

RESULTS

Figure 1 shows displacement adaptation as a function of exposure time for the three initial groups. The circles represent the mean level of adaptation (LA), in degrees, for subjects receiving only displacement. The triangles represent the LA for subjects receiving only tilt. And the combination of triangle and circle shows performance for subjects receiving the combination of tilt and displacement. The smoothed curves represent the best-fit exponential functions determined by the method of least squares. The functions employing three parameters for 10 data points fit the data reasonably well for descriptive purposes, yielding a standard error of estimate[1] of 0.53. Clearly, the simultaneous presence of tilt had no effect on displacement adaptation. Analysis of variance indicates a main effect for groups, $F(2,45) = 47.75$, $p < .001$, and orthogonal comparisons indicate that displacement adaptation when both tilt and displacement are present is not different from that found when only displacement was present, $F(1,45) = 0.07$. Furthermore, both groups receiving displacement show significantly greater displacement adaptation than does the group receiving only tilt, $F(1,45) = 95.43$, $p < .001$. At none of the test does displacement adaptation in the tilt-only group exceed the 95% confidence limits inclusive of zero, and the average adaptation (0.24) is well within these confidence limits (0.48). Furthermore, the Groups by Time interaction is significant, $F(8,180) = 3.13$, $p < .005$, indicating that while the displacement-only and the tilt-and-displacement groups show increasing displacement adaptation over the exposure interval, essentially no change in judged location occurred when only tilt was present.

Analysis of the tilt adaptation scores for the four groups comprising the factorial combination of two levels of tilt (18° and 20°) and two levels of combination of the two transforms (tilt-only and tilt-and-displacement) revealed no significant differ-

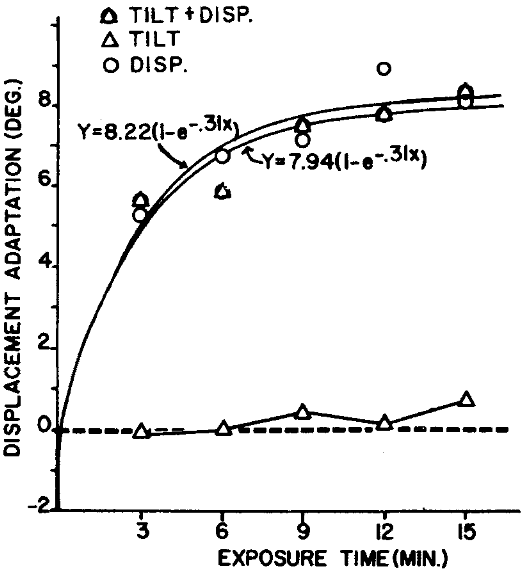

Figure 1. Mean level of adaptation to optical displacement as a function of exposure time for groups receiving only displacement (circles), only tilt (triangles), and the combination of displacement and tilt (circles and triangles). (Smooth curves represent the best fit by the method of least squares.)

ences among the groups. While tilt adaptation differed in the expected direction between groups receiving 18° ($\bar{X} = 3.17$) and 20° ($\bar{X} = 4.36$), this difference was not significant, $F(1,60) = 1.21$, and this factor did not interact with the combination of transforms, $F(1,60) = 0.48$. These data were consequently combined with the tilt adaptation scores for the original displacement-only group and data for the resultant three groups was subjected to an unequal cell frequencies analysis of variance.

The results for tilt adaptation show a picture similar to that for displacement adaptation, although less clearly due to greater variability of the orientation judgments. Figure 2 shows tilt adaptation as a function of exposure time for the three groups. The circles, triangles, and combinations of circle and triangle represent, respectively, the groups receiving displacment only, tilt only, and combination of displacement and tilt. The descriptive, exponential functions employing three parameters for 10 data points fit the data reasonably well, yielding a standard error of estimate of 0.31. No significant difference occurred between tilt-only and tilt-and-displacement conditions. Analysis of variance indicates a main effect for groups, $F(2,77) = 4.11$, $p < .025$; however, orthogonal comparisons indicated that this effect lies between the displacement-only group and the groups receiving tilt, $F(1,77) = 7.88$, $p < .01$. The persistent inferiority of the tilt-and-displacement group relative to the tilt-only group, at all tests, is not significant, $F(1,77) = 0.36$, and is primarily due to three subjects who showed unusually large negative shifts, particularly at the 9-min test. There is a tendency for the displacement-only group to show shifts in orientation judgments in the adaptive direction, increasing over tests. However, at no point is the shift significantly different from zero, and the average change (0.14) is well within the 95% confidence limits (1.46) inclusive of zero. Exposure time is a significant source of variance, $F(4,308) = 3.24$, $p < .025$; however, the Groups by Time interaction is not significant, $F(8,308) = 0.30$. Tilt adaptation, per se, appears to be asymptotic within the exposure period, while the orientation of responses tends to shift in a counterclockwise (in this case, adaptive) direction even in the absence of optical tilt. However, substantial tilt adaptation is obtained beyond this effect.

CONCLUSION

Visuomotor adaptation to optical tilt and displacement simultaneously is not different from adaptation to each transform separately. These results suggest the conclusion that visuomotor compensation for optical tilt and optical displacement is mediated by separate and independent adaptive systems. This conclusion is consistent with what may be called a disjunctive view of visuomotor behavior. The disjunctive view assumes that locus-specific analysis is necessary in determining the location of an object, while only relational analysis is involved in specifying the relative orientation between parts of the object. These two kinds of processes are presumed to

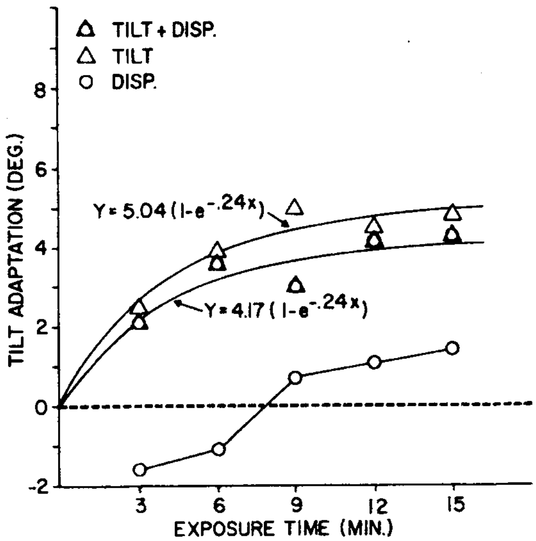

Figure 2. Mean level of adaptation to optical tilt as a function of exposure time for groups receiving only displacement (circles), only tilt (triangles), and the combination of displacement and tilt (circles and triangles). (Smooth curves represent the best fit by the method of least squares.)

occur simultaneously and independently of one another (i.e., in parallel), and, since displacement and tilt are assumed to affect different processes, the two transforms do not interact in affecting adaptation.

Since the present results, which emphasized visuomotor performance, are not different from previous results (Redding, 1973a), which emphasized visual judgments, it seems unnecessary to posit different kinds of adaptation for the two experimental paradigms. Regardless of whether pointing or purely visual judgments are required, adaptation to both tilt and displacement simultaneously is not different from adaptation to each transform separately. Most studies of visuomotor coordination have employed optical displacement, while studies of purely visual adaptation have typically involved optical tilt. Present results suggest that differences in results between the two paradigms may arise because different transforms are involved and, hence, different kinds of perceptual analyses are required, not because the exposure and test procedures are different.

REFERENCES

Garner, W. R., & Morton, J. Perceptual independence: Definitions, models, and experimental paradigms. *Psychological Bulletin*, 1969, **72**, 233-259.

Harris, C. S. Adaptation to displaced vision: Visual, motor, or proprioceptive change? *Science*, 1963, **140**, 812-813.

Harris, C. S. Perceptual adaptation to inverted, reversed, and displaced vision. *Psychological Review*, 1965, **72**, 419-444.

Held, R. Exposure-history as a factor in maintaining stability of perception and coordination. *Journal of Nervous and Mental Disease*, 1961, **132**, 27-32.

Held, R. Dissociation of visual functions by deprivation and rearrangement. *Psychologische Forschung*, 1968, **31**, 338-348.

Held, R. Two modes of processing spatially distributed visual stimulation. In *The neurosciences: Second study program*. New York: Rockefeller University Press, 1970.

Held, R., & Gottlieb, N. Technique for studying adaptation to disarranged hand-eye coordination. *Perceptual and Motor Skills*, 1958, **8**, 83-86.

Ingle, D. Two visual mechanisms underlying the behavior of fish. *Psychologische Forschung*, 1967, **31**, 44-51.

Mikaelian, H. H. Relation between adaptation to rearrangement and the source of motor-sensory feedback. *Psychonomic Science*, 1967, **9**, 485-486.

Redding, G. M. Simultaneous visual adaptation to tilt and displacement: A test of independent processes. *Bulletin of the Psychonomic Society*, 1973, **2**, 41-42. (a)

Redding, G. M. Visual adaptation to tilt and displacement: Same or different processes? *Perception & Psychophysics*, 1973, **14**, 193-200. (b)

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

Schneider, G. Contrasting visuomotor functions of tectum and cortex in the golden hamster. *Psychologische Forschung*, 1967, **31**, 52-62.

Schneider, G. Two visual systems. *Science*, 1969, **163**, 895-902.

Travarthen, C. B. Two mechanisms for vision in primates. *Psychologische Forschung*, 1968, **31**, 299-337.

NOTE

1. A multiple curve-fitting procedure was employed where two equations were fit simultaneously to the two sets of data, reflecting the fact that no significant differences were found between the two groups. A single rate parameter was estimated for both groups and the asymptote parameter was allowed to vary in order to reflect numerical differences between groups. The single goodness of fit statistic for this procedure is the standard error of estimate, defined as the square root of the averaged squared deviation of obtained from predicted LA for each of the 10 data points.

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