Adaptation to displaced vision: Amount of optical displacement and practice¹

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The influence of two variables, length of exposure and amount of optical distortion, on adaptation to displaced vision was examined. The extent of adaptation was positively related to number of trials in a task involving spatial localization of a target displaced by a wedge prism. A substantial adaptation (38%) was produced after only two trials. The adaptation was also positively related to degree of optical displacement, except at the highest level used. The findings are discussed in terms of availability of information about the discrepancy between vision and task.

Research on adaptation to transformed visual input has employed a variety of procedures and types of exposure to optical devices that alter the visual input. For inducing lateral displacement by wedge prisms, typically an exposure period of a few minutes (e.g., Held & Gottlieb, 1958) or 20 to 90 trials of pointing at a target (e.g., Harris, 1963) have been used in short-term or one-session experiments, and up to 144 h of exposure (e.g., Hay & Pick, 1966) have been employed to study long-term effects. The degree of optical distortion has also varied widely among different experiments, with the most frequent distortion being 11.3 deg (produced by a 20-diopter wedge prism).

The amount of adaptation (usually measured in terms of the negative aftereffect) varies greatly depending on the technique used and the condition of exposure to the optical device. Freedman (1968) has made a direct comparison of three of these techniques—the methods of Held and Gottlieb (1958), Harris (1963), and Howard (1968). He demonstrated that the first method produces a great deal less adaptation than do the others.

In view of the great variety of procedures used in studying adaptation to displaced vision, it would seem desirable to have a systematic study of the two main variables mentioned above—amount of practice or length of exposure to the optical device and amount of displacement produced by the optical device. A number of studies have shown a positive relationship between amount of exposure and degree of adaptation to distortion (Hamilton, 1964; Held & Bossom, 1961; Held & Hein, 1958; Ebenholtz, 1966; Wertheimer & Arena, 1959). Only two of

these (Hamilton and Held & Hein) have involved the typical situation of a wedge prism used with an exposure period of short duration (less than 1 h).

Studies on the relationship between the amount of distortion and adaptation have been conducted on adaptation to tilt by Morant and Beller (1965) and Ebenholtz (1966). Both of these report a positive relationship between adaptation and degree to tilt. These two variables (amount of distortion and length of exposure) were examined in a recent study by Efstathiou (1969). She reports a positive, negatively accelerating function relating amount of adaptation to exposure time (up to 30 min). In addition, she found a positive relationship between amount of adaptation and degree of prismatic displacement up to 9 deg, with a sudden decrease at a displacement of 13.7 deg (24-diopter wedge prism). The first finding, that some asymptotic value would be reached after a certain length of time, seems reasonable. However, the second finding of a decrease in adaptation at the highest displacement is unexpected and difficult to interpret.

A limiting feature of Efstathiou's experiment was the use of the technique of Held and Gottlieb (1958). Freedman (1968) has demonstrated that this technique produces substantially less adaptation (about one-fourth as much) as do other techniques such as those of Harris (1963) and Howard (1968). The limited adaptation produced by her technique could well be due to the lack of a target to which the S must point during exposure to the prism. Welch (1969) has shown that the degree of adaptation is directly related to the specificity of the target, the least adaptation occurring when no target was present. His interpretation of this was in terms of the amount of information available to the S under the various conditions. When the S points to a target and receives feedback about the correctness of his response, he has more information than when he receives feedback about the position of his hand in space without reference to some target. With this limitation in mind, it was felt that Efstathiou's (1969) experiment may not have completely answered the problem of the relationship between adaptation and length of exposure and degree of distortion. In addition, an unexpected

feature in Efstathiou's experiment was the lack of a significant aftereffect in the 2-, 4-, and 8-diopter groups after 5 min of exposure. In view of the very rapid adaptation (45.4% after a "short glimpse" of about 1 sec) reported by Wertheimer and Arena (1959), a 5-min exposure would seem sufficient to produce adaptation, even under the conditions used by Efstathiou. The following experiments were conducted to provide further information on the problem.

EXPERIMENT 1

Subjects

The Ss were volunteer senior high-school students of both sexes between the ages of 16 and 19 years. All Ss were right-handed.

Apparatus

The apparatus was a modification of that used by Goldberg, Taub, and Berman (1967). It was constructed of plywood, painted flat black, and set on a table of normal height. Attached to the front of the apparatus was a chin rest and a holder in which was fixed a pair of modified welder's goggles with either plain glass or 20-diopter wedge prism before the right eye. The left eye was occluded by opaque material. Monocular vision was used because it tends to lead to greater adaptation and avoids some of the problems associated with convergence at close distances (Freedman & Rekosh, 1968, p. 159). The S's field of vision was approximately 20 deg, both horizontally and vertically. Eight inches in front of S's eye was a window that could be opened by E. Ten inches beyond it was an identical window that could also be opened by E. Between the two windows (13 in. from S's eye) was a track along which the target (a 4-in., ¼-in.-diam, vertical wooden rod) could be moved horizontally. When the front window was open, S could see only the target. When both windows were open, S could see through to the back of the apparatus (a plain flat-black background). On the underside of the apparatus was a scale that could be read to the nearest ¼ in. by viewing a reflection of the scale in a mirror on the table under the apparatus.

Procedure

The S was given a set of instructions to read, and any questions about them were

answered before the experiment began. The S's task was to locate the target by reaching under the apparatus with his right hand, to the index finger of which was attached an L-shaped pointer, so that the pointer came up at the back of the apparatus behind the target in line of sight with it. After each response, S put his hand back on the table. S kept the left hand on his lap at all times. At the beginning of each trial, the front window was closed and the target was placed in 1 of 11 predetermined random positions (straight ahead of S's right eye and 5 positions on each side of the center, at ½-in. intervals). The front window was opened so that S could see the target. He then made his response by reaching under the apparatus. Between trials the front window was closed so the target could be set at a new position. The experiment was carried out in three phases.

Phase 1. This phase consisted of 40 trials, in blocks of 10, with each block separated by a 30-sec rest. The second window was not opened, so Ss received no feedback about the correctness of their responses. The first 30 trials were not recorded but served as practice trials intended to stabilize responses and familiarize S with the procedure. Goldberg et al (1967) used 60 practice trials, but preliminary investigation suggested that 30 was sufficient. The last 10 trials were recorded and constituted the preexposure measure of the S's ability to locate the target. Between blocks of 10 trials, S sat back in his chair, closed his eyes, and relaxed for 30 sec. During this rest interval, E changed the goggles—removed the set of goggles that had plain glass in them and replaced these with another pair of identical goggles. This was done so that Ss would not be aware of changes to be made in the goggles later in the experiment.

Phase 2. During the 30-sec rest following the last trial of Phase 1, the plain glass goggles were replaced by goggles with a 20-diopter wedge prism before the right eye. This produces a lateral displacement of 11.3 deg. During this phase of the experiment, a specified number of trials was administered. After S had reached for the target on each trial, E opened the back window so that he could see the position of the pointer and thus receive feedback about the accuracy of his response. The S was allowed to see the pointer for approximately 1 sec, and then both windows were closed so that the target could be set for the next trial. The S put his arm back on the table. At the end of this phase, S took another 30-sec rest while E exchanged the prism goggles for the plain glass goggles.

Phase 3. This was identical to Phase 1,

except that only 10 trials were administered. These trials constituted the postexposure measure of accuracy of localization of the target.

Half of the Ss in each group viewed the target with the prism base to the left and half with the base to the right. The difference between the preexposure and the postexposure measures of localization constituted the aftereffect of the displaced vision. In each experimental condition, a different amount of practice was given (5, 15, or 25 trials) in Phase 2. There were 12 Ss in each group.

Results and Discussion

The magnitude of the aftereffect was directly related to the number of trials ($F = 11.27$, $df = 2/33$, $p < .001$). The aftereffect was 1.27 in. for the 5-trial group, 1.70 in. for the 15-trial group, and 2.90 in. for the 25-trial group. The maximum expected aftereffect (based on a displacement of 11.3 deg at a distance of 20 in.) was 4.0 in. Therefore, the 25-trial group reached approximately 73% of complete adaptation.

EXPERIMENT 2

In view of the fairly substantial adaptation (32%) with just five trials, the same experiment, with the same number of Ss in each group, was repeated using two- and four-trial groups. Ss were volunteer high-school students from the same population. Results indicated an adaptation of 1.5 in. for the two-trial group and 1.8 in. for the four-trial group. It can be seen that even two trials brought about a substantial adaptation. There were no significant differences among the adaptations of the 2-, 4-, 5-, and 15-trial groups. On the basis of these findings, it appears that Wertheimer and Arena (1959) were correct in stating that a very small amount of exposure to or information about the discrepancy between vision and touch is sufficient to bring about a substantial degree of adaptation. In addition, the technique used here seems capable of producing a considerable amount of adaptation within a few trials.

Since some Ss began with a fairly large initial error during the preexposure trials, it was considered desirable to examine the relationship between initial error and amount of adaptation. It was possible that some Ss were simply becoming more accurate after a number of trials rather than showing an adaptation to the displaced visual input. The correlation between the amount of adaptation and the magnitude of error before exposure to the displacing goggles ($r = .23$) was not statistically significant. Therefore, the differences between the pre- and

postexposure measures cannot be attributed simply to a reduction in the errors in localization per se.

EXPERIMENT 3

A second procedural factor to be examined was the amount of optical distortion to which Ss are exposed. It may seem obvious that the greater the distortion, the greater will be the adaptation produced. This is correct in an absolute sense but not necessarily in a relative sense. Intuitively, one might expect, for example, 50% adaptation at any specific level of distortion. But this would depend in part on how the S was interpreting the visual input and how much information was available to him about the discrepancy between touch and vision. If the S attempts to reach out to touch the target he is viewing through a 20-diopter wedge prism, it is evident to him that there is a great discrepancy between where the target is and where it looks to be. On the basis of this information he then adjusts his next response. Eventually this correlation leads to more or less complete compensation for the discrepancy. However, if the S is exposed to the same experimental procedure while viewing a target through a 2-diopter wedge prism, he has practically no information about the discrepancy between the two senses. The slight error (1 deg), which he will make initially, may be interpreted as random error or lack of ability on his part. When Ss see the extent of their errors under conditions of visual displacement, they often comment spontaneously about their poor motor coordination.

On the basis of this reasoning, it seems plausible that the *relative* amount of adaptation to displaced vision will be directly related to the amount of distortion. That is, the greater the distortion, the greater the *proportion* of adaptation.

This is essentially what Efstathiou (1969) has reported, except that the two smallest displacements (2- and 4-diopter prisms) produced virtually no adaptation, and the greatest displacement produced an unexpected and unexplained decrease in adaptation following a systematic increase up to 16 diopters (8.95 deg).

The third experiment examined further the relationship between adaptation and amount of optical displacement in an attempt to clarify some of the earlier findings on this problem.

Subjects

The Ss were volunteer male university students between the ages of 18 and 28 years. All Ss were right-handed.

Apparatus and Procedures

The apparatus and procedure were

Fig. 1. Percent of maximum adaptation (negative aftereffect) as a function of amount of optical displacement.

identical to those in Experiment 1 with the following exceptions. During exposure to the wedge prism, the range of settings of the target was restricted to 6, as opposed to 11 settings used in the previous experiments. The settings used were those that caused the target to appear to be closer to the center of the visual field when viewed through the prism. In the case of the base-right prism, it was the settings from the center to 2½ in. to the right (in ½-in. steps); in the case of the base-left prism, it was the same to the left. The reason for this was to keep the targets closer to the center of S's visual field while he was viewing it. On the basis of the first experiment, it was found that there was relatively more variability at the extreme settings. At these settings the target looked to be far off to one side of the visual field, to the extent that if S misjudged the target by much more than the deviation produced by the prism, he might be so far off as to be unable to see the position of his pointer. This never occurred, but the change in procedure was done to prevent this possibility.

Four groups of eight Ss were used. Each group viewed the target during Phase 2 through a prism of a different strength (2, 4, 6, 8, 12, 16, 20, or 25 diopters). Ten trials were administered during Phase 2.

Results and Discussion

The absolute amount of adaptation increased as the degree of displacement increased ($F = 2.92$, $df = 7/56$, $p < .025$). In addition, the *proportional* amount of adaptation was directly related to the degree of displacement. Figure 1 indicates this relationship.

The 2-diopter prism did not produce an aftereffect greater than zero. However, all of the other prism strengths, except the 8-diopter prism which did not reach

statistical significance ($p < .07$), produced a significant adaptation to the displaced vision.

These data support the suggestion that the greater the distortion, the greater the proportional adaptation. If this effect is due in part to greater information concerning the discrepancy between the two senses under conditions of greater distortion, one might expect that such conditions would lead to more rapid improvement in the task (more accurate localization of the target) during exposure to the prisms. An examination of the reduction of the pointing errors during prism exposure indicates a more rapid decrement in the error for groups exposed to larger distortions (see Table 1). These findings lend support to the argument proposed earlier, that the greater displacement provides relatively more information about discrepancy between vision and touch, leading to a more rapid correction of the pointing error.

The present results support some, but not all, of Efstathiou's (1969) findings. There are certain basic differences between the procedure used here and that used by Efstathiou, who suggests that there was less adaptation in her experiment than in others because of a constraint of the hand movement. An additional factor would seem to be the lack of a target to which the S points (Welch, 1969). The total amount of exposure in the present experiment was somewhat less than even the 5 min of exposure in Efstathiou's experiment. Each trial involved not more than 2 sec of exposure to the displaced visual input. Therefore, the S had no more than 50 sec of total exposure even in the 25-trial group of Experiment 1. It seems that the exposure from trial to trial accumulates, as was found by Held and Hein (1958). Only the work by Wertheimer and Arena (1959) corresponds to the present study in terms of a relatively large effect after a very brief exposure to displacement. It is evident that more research is required before we will understand the influence of even these

basic parameters on adaptation to displaced vision.

One unexpected finding in both the present study and the one by Efstathiou (1969) was the sudden decrease in aftereffect at the greatest displacement. It appears not to be due to chance or error, since it is so marked an effect in both experiments. The following explanation may account for the phenomenon. With relatively small displacements, the S is most probably unaware of the introduction of an optical device that distorts his vision. Even with a 20-diopter prism in this and other experiments (Dewar, 1970), Ss spontaneously commented on their own lack of ability or poor motor coordination during the prism exposure phase of the experiment. However, a point would be reached (possibly just beyond a prism strength of 20 diopters) at which S would become aware of the displacement because it was so large. Under those circumstances, the S would consciously compensate for the displacement and thus not undergo the usual visual and proprioceptive changes that apparently take place during prism adaptation.

The findings related to the degree of improvement during the task at different levels of initial difficulty (assuming the task difficulty is related to prism strength here) are parallel to those reported by the author (Dewar, 1967) on a different perceptual learning task. It was shown that the amount of decrement in the magnitude of the Müller-Lyer illusion with practice was a direct function of the initial difficulty of the task. Figures that produced a relatively large initial illusion led to a more rapid decrement than did those that were easier to judge (produced less illusion). Those findings were interpreted in terms of attention to the relevant aspects of the stimulus (the horizontal lines of the illusion figure). It was argued that figures that are initially more difficult demand greater attention on the part of the S, therefore, lead to more rapid perceptual learning. It seems

Table 1
Percentage of Maximum Error During Prism Exposure

Prism Strength (Diopters)	Maximum Error* (Inches)	Trials									
		1	2	3	4	5	6	7	8	9	10
2	0.4	100	95	0	78	140	78	8	48	-63	48
4	0.8	82	50	70	28	48	11	70	35	15	15
6	1.2	104	68	73	60	68	47	49	60	3	42
8	1.6	100	88	100	75	56	56	38	56	69	62
12	2.4	100	42	18	29	12	12	33	9	9	12
16	3.2	72	59	31	16	14	12	25	3	19	6
20	4.0	98	88	48	32	18	8	8	15	5	8
25	5.0	86	62	48	19	17	21	22	9	12	4

* Maximum error refers to the error in localization of the target which would be expected if S's response was determined entirely by where the target appeared to be while viewing it through the prism.

reasonable to put the same interpretation on the present findings. That is, since it is more difficult to localize a target that is displaced 4 in., as compared with one displaced 0.4 in., the S soon realizes that he has to pay greater attention to what he is doing in order to perform the task correctly. Singer and Day (1966) have shown the importance of attention in adapting to displaced vision. These findings also support the postulates of Gibson (1966), Newbigging (1965), and Wohlwill (1966), all of whom stress the importance of attention in the perceptual learning process.

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NOTES

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