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Mechanisms underlying the slant aftereffect

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Transfer of the median plane slant aftereffect was assessed across changes in the type of depth information for the slant of the display. In addition, the effectiveness of monocular-pictorial and binocular information in inducing the aftereffect was measured. Binocular information produced a larger aftereffect than did monocular-pictorial information, and adaptation created with one type of depth information induced an aftereffect assessed with presentation of the other type of depth information. The results suggest that the slant aftereffect is not entirely specific to type of depth information presented. The induction of the aftereffect involves a process more general than the sensory mechanisms responsible for adaptation to two-dimensional tilt or adaptation to a texture gradient.

When a visual stimulus slanted toward or away from a subject is inspected for a prolonged period of time, a "median plane slant aftereffect" is induced, in which the subject judges an objectively vertical stimulus to be slanted in the direction opposite the inspection slant. When tested with an adjustment technique which involves the subject's setting the test stimulus to vertical, the aftereffect results in an adjustment error in the direction of the inspection stimulus. The existence of the slant aftereffect has been established by research over the past three decades (Bergman & Gibson, 1959; Kohler & Emery, 1947; Wenderoth, 1970, 1971; Wenderoth, Rodger, & Curthoys, 1968).

Coltheart (1971) has explained the slant aftereffect in terms of a feature analyzer model, which assumes the existence of slant detectors with the properties of both angle specificity and adaptability. According to this model, the peak or weighted average of the activity of many detectors is analyzed at a higher level in the system. The model accounts for a slant aftereffect in terms of a shift in the central tendency of detector activity induced by prolonged inspection of a stimulus at a given angle of slant.

Both Coltheart (1971) and Wenderoth (1971) have suggested further that at least one type of information utilized by these slant analyzers may be the two-dimensional tilt of contours received by each eye when viewing a slanted surface. The distinction is made here between tilt in two dimensions and slant into the third dimension. Wenderoth (1971) proposes that the binocular slant aftereffect may be a complex case of tilt aftereffect in which directionally opposite tilt effects are induced at the two eyes. This theory is consistent with neurophysiological evidence on tilt detectors (e.g., Hubel & Wiesel, 1962) and slant detectors (Blakemore, Fiorentini, & Maffei, 1972).

However, in contrast to theories which stress binocular mechanisms for the slant aftereffect, there is evidence that aftereffects can be obtained without binocular depth cues. Bergman and Gibson (1959) reported that slant aftereffects may be obtained with either monocular or binocular stimulation, with little difference in magnitude, when a highly textured burlap surface is used as the adaptation stimulus. Moreover, while Kohler and Emery (1947) report that the most convincing aftereffects were obtained with binocular adaptation, they did note a significant aftereffect when an observer monocularly inspected a slanted stimulus and then judged the slant of a binocularly viewed stimulus presented in the frontal plane. They also mentioned the possibility of an aftereffect induced by inspection of a stimulus

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providing only pictorial slant information; however, they stated that their own demonstrations had not been entirely conclusive.

Such findings suggest that the slant aftereffect may not be limited to cases where binocular information is available. Indeed, Kohler and Emery (1947) have suggested that the slant aftereffect may be a generalized effect in which "the three dimensional appearance of the (inspection) situation is more important than the particular cues which give rise to that appearance" (p. 193). In this context, Experiment 1 investigates the effectiveness of purely binocular information (convergence and disparity) and purely monocular information (linear perspective and a texture gradient) in creating a slant aftereffect. The experiment focuses on the possibility that adaptation created with one type of depth information will produce an aftereffect when depth is specified by a different type of depth information.

EXPERIMENT 1

Method

Subjects. Thirty-six undergraduate students from an introductory psychology class participated in this experiment. An equal number of males and females took part.

Apparatus. The display cards were mounted on a frame which the subject could manually slant through the median plane by turning a knob with his or her left hand. The cards were viewed from a distance of 41.6 cm through a conical black tube which tapered to a small oval aperture. The resulting visual field was 10°2′ (horizontal) × 7°52′ (vertical). Shutters were used to provide binocular or monocular viewing conditions and also to occlude the displays between inspection and test periods. A headrest reduced gross movements. Slant measurement was made relative to gravitational upright and was accurate to 0.5°.

The display cards were illuminated by a ringed fluorescent light. Three display patterns were used, drawn in black lines, .25 mm thick, on white paper. The first pattern was a single vertical line, appearing in the center of the binocular visual field. The second pattern was a square grid, each cell side measuring 6.4 mm. When viewed through the tube, nine vertical lines were visible when the pattern was in the frontal plane. The third pattern was a trapezoidal grid which was the optical equivalent of the second pattern slanted at 45°. The leftmost and rightmost lines were tilted 3.5° from vertical.

Procedure. The four conditions of the experiment are shown in Table 1. "Viewing mode" refers to the manner, either monocular or binocular, in which the display was viewed. The "inspection" segment refers to the period of adaptation to the display pattern, and the "test" segment refers to the procedure involving adjustment of the display to perceived vertical. Slant specified by positive degrees indicates a display card with the top edge slanted toward the viewer; slant in negative degrees indicates a display card with the top edge away from the viewer.

Four conditions were examined: in two conditions, the depth information was the same during the inspection and test segments (binocular-binocular and monocular-monocular); in the remaining two conditions, depth information differed, testing a transfer across slant information between inspection and test segments (binocular-monocular and monocular-binocular). Within each condition, an experimental inspection phase and a control inspection phase were included. In the experimental inspection phases, the displays provided either pictorial slant or binocular slant information. The displays used in the control phases provided information for a fronto-parallel surface and were not expected to result in aftereffects. In all test segments, the subject's task was to adjust the pattern to the perceived upright position.

Each subject received two of the four conditions described in Table 1. Each subject viewed the inspection pattern both binocularly and monocularly, but the pattern was presented under only one viewing mode for the test. The order of viewing modes and the order of experimental and control phases were counterbalanced across subjects. In addition, the orientation of the inspection surfaces and the starting position of the test displays were randomized across subjects. For all monocular presentations, the subject viewed the display with his or her dominant eye.

For both experimental and control phases of a condition, the display pattern set at the appropriate slant was viewed for 90 sec. The shutter was closed for a 5-sec period while the pattern was changed, and opened for the test. The subject then adjusted the pattern until it appeared to be upright, and the angle of adjustment was recorded. After a 5-sec period with the shutter closed, the inspection segment was then reinstated for 30 sec. In this manner, four inspection and four test segments were alternated. The second through fourth inspection segments were only 30 sec in duration, since the aftereffect from the initial inspection segment had not dissipated entirely and it took a shorter period of time to reinstate it. The time interval between experimental and control phases and between the two conditions received by each subject was 5 min.

Results

In order to provide a sensitive measure of aftereffect magnitude, difference scores were computed

Table 1
Conditions in Experiment 1

	Binocular-Binocular	Monocular-Monocular	Binocular-Monocular	Monocular-Binocular
Inspection Segment				
Viewing Mode	Binocular	Monocular	Binocular	Monocular
Experimental Phase Pattern	Vertical Line ±45° slant	Trapezoidal grid 0° slant	Vertical Line ±45° slant	Trapezoidal grid 0° slant
Control Phase Pattern	Vertical Line 0° slant	Square Grid 0° slant	Vertical Line at 0° slant	Square Grid 0° slant
Test Segment				
Viewing Mode	Binocular	Monocular	Monocular	Binocular
Test Pattern (experimental and control)	Vertical Line	Square Grid	Square Grid	Vertical Line

for each subject by subtracting the mean of the four adjustment settings in the control phases from the mean of the four adjustments in the experimental phases. The means, standard deviations, t values, and p values for the four conditions are presented in Table 2. One-tailed t tests revealed that all four aftereffects were significantly greater than zero. A 2 by 2 mixed analysis of variance was performed on the difference scores in the four conditions to assess the effects of type of depth information available during the inspection and test segments of the experiment on the slant aftereffect. There was a significant main effect of the type of information presented in the inspection segment, $F(1,34) = 4.36$, $p < .05$. The binocularly viewed line slanted in real depth was a more effective inspection display than the monocularly viewed trapezoidal grid with only pictorial slant. The type of depth information presented in the test segments resulted in a nonsignificant difference in the amount of aftereffect. There was significant interaction between type of depth information and the inspection and test segments, $F(1,34) = 15.50$, $p < .001$, as illustrated in Table 2. This interaction reflects the superiority of same-cue over cross-cue aftereffects. When the test segment provided binocular information, binocular inspection produced aftereffects of greater magnitude than did monocular inspection, $t(17) = 4.56$, $p < .001$. For monocular test segments, monocular inspection yielded aftereffects of greater magnitude than did binocular inspection, although the effect was not significant, $t(17) = .55$, $p > .20$.

Discussion

In addition to the aftereffect induced by binocular information, an aftereffect was produced in the conditions involving monocular-pictorial information. Of particular interest is the finding of monocular-binocular and binocular-monocular aftereffects. This result is consistent with a slant detection capability which is not specific to either binocular and monocular stimulation, but superordinate to both.

Table 2
Means, Standard Deviations, and t Values of Four Aftereffects (Experiment 1)

	Inspection Condition[a]	
Test Group	Monocular	Binocular
Monocular		
M[b]	2.67	2.17
SD	2.83	2.42
t[c]	4.00**	3.80**
Binocular		
M	.92	3.97
SD	1.74	2.67
t	2.23*	6.30**

[a]*Each subject received both inspection conditions.* [b]*Means and standard deviations are expressed in degrees, and based on 18 scores.* [c]*Based on one-tailed t tests (17 df).*
*$p < .025$
**$p < .001$

EXPERIMENT 2

In addition to the explanation proposed in Experiment 1, that the resulting cross-cue aftereffects suggest a superordinate adaptation process, there are at least two other explanations for these cross-cue aftereffects. One account for the transfer across information type is Wenderoth's (1971) proposal that the binocular slant aftereffect may be a complex case of tilt aftereffect. Since the patterns used in all conditions in Experiment 1 contained contours, the experiment does not rule out the possibility that aftereffect transfer across information type was due to adaptation of two-dimensional contour tilt detectors.

If, however, the slant aftereffects observed are mediated by a mechanism more general than the adaptation of two-dimensional contour tilts, we would expect an aftereffect to occur when subjects who adapt monocularly to a pictorially slanted grid are transferred to a randomly textured sandpaper display. If adaptation does require lines in the display, no aftereffect should be observed.

A second explanation for the results of Experiment 1 is the adaptation of hypothetical detectors for the gradient of texture. If the adaptation of texture gradient detectors produced those results, due to the texture of the paper on which the display patterns were drawn, we would expect transfer of aftereffects to a fine-grain sandpaper surface following adaptation to a pictorially slanted grid. Moreover, the transfer would be expected to occur equally for binocular and monocular test conditions.

Method

Subjects. The subjects were 16 undergraduate students from an introductory psychology class (7 males and 9 females). These subjects did not participate in the first experiment.

Apparatus. The apparatus was the same as that used in Experiment 1. The displays used were the trapezoidal grid pattern representing pictorial information for a surface slanted at −45°, the square grid pattern, and a sheet of 3M 120 production sandpaper.

Design and Procedure. The experiment was designed to test the monocular-binocular condition as one of cross-cue transfer. After several practice adjustments, each subject was presented with experimental and control phases of a single inspection viewing mode, and both modes for the test segment. The procedure was similar to that used in Experiment 1.

For the monocular-binocular condition, the experimental inspection display was the trapezoidal grid, set in the frontal plane and viewed with the dominant eye. The control inspection display was the square grid figure, again set in the frontal plane and viewed monocularly. In the test, the sandpaper was adjusted to perceived vertical from a +45° or −45° starting position under binocular viewing. In the monocular-monocular condition, the subject again monocularly inspected the trapezoidal grid in the experimental phase, and the square grid in the control phase. For the test, the subject set the sandpaper display to perceived vertical from a +45° or −45° starting position, viewing the display monocularly with the dominant eye. The order of conditions was counterbalanced across subjects.

Results

The aftereffects obtained when the sandpaper was binocularly viewed was 1.65°, $t(15) = 2.79$, $p < .01$, by a one-tailed test. When the sandpaper was viewed monocularly, the aftereffect was much smaller, 65°, and was not significantly greater than zero, $t(15) = .94$, $p > .20$ (one-tailed).

Although the aftereffect did not reach a level of significance when tested monocularly, the difference between the aftereffect in the two conditions was not significant, $t(15) = 1.20$, $p > .20$.

Discussion

The significant result is that a reliable aftereffect did occur when subjects monocularly inspected a pictorially slanted trapezoidal grid and transferred to binocularly viewed sandpaper on which no lines appeared. This finding should rule out the hypothesis that transfer of the slant aftereffect is due entirely to adaptation of two-dimensional tilt detectors.

However, this experiment does not exclude the possibility that the texture gradient created by the grid during the inspection period could be mediating an aftereffect that is present when the sandpaper is viewed, since the difference between the magnitudes of the aftereffect in the monocular and the binocular test conditions did not reach significance.

EXPERIMENT 3

To test the hypothesis that commonality of texture gradient accounts for the slant aftereffect, a third experiment was performed in which subjects viewed a single line either monocularly or binocularly during the inspection period, and were tested with a monocularly viewed square grid. The monocular inspection of the single-line display should control for any texture gradient adaptation during the inspection period. If (a) no significant aftereffect were induced by monocular inspection of the line, (b) a significant aftereffect were produced by binocular inspection of the line, and (c) the difference between the two aftereffects were significant, then we would have evidence of transfer which could not be accounted for by the commonality of texture gradient information during the inspection and test periods.

Method

Subjects. Sixteen undergraduate students from an introductory psychology class served as subjects (7 males and 9 females). These subjects did not participate in either the first or second experiment.

Apparatus. The apparatus was the same as that used in Experiment 1. The display patterns used were a single vertical line, appearing in the center of the binocular visual field, and a square grid pattern.

Design and Procedure. The experiment was designed to test the binocular-monocular condition as one of cross-cue transfer. After several practice adjustments, each subject was presented with experimental and control phases of both viewing modes during inspection and a single test mode. The procedure was similar to that used in Experiments 1 and 2.

In the binocular-monocular condition, the single vertical line was presented for binocular inspection. The display was slanted at +45° or −45° during the experimental phase, and was upright for the control phase. In the test, the subject adjusted the square grid to perceived vertical, viewing it monocularly with the dominant eye. For the monocular-monocular condition, the subject viewed the vertical line display monocularly. Again, he or she was presented with an experimental phase with the display at +45° or −45° slant (pilot subjects reported that the line did not appear to be slanted in depth) and a control phase with the display vertical. The monocular test segment involved the subject's adjusting the square grid to perceived vertical. The order of condition was counterbalanced across subjects.

Results

The mean size of the aftereffect obtained for a binocular-monocular condition was 2.72°. This effect was significantly greater than zero, $t(15) = 3.94$, $p = .001$ (one-tailed). The mean aftereffect when the inspection display was viewed monocularly was .41°, and was not significantly greater than zero, $t(15) = .78$, $p > .20$ (one-tailed). The mean difference between the aftereffect induced by monocular inspection or by binocular inspection was 2.57°. This difference was significant, $t(15) = 2.92$, $p < .01$ (one-tailed).

Discussion

Binocular inspection of a single-line display induced an aftereffect that was apparent when the square grid display was viewed monocularly during the test. When the line was inspected monocularly, no significant aftereffect was produced. Moreover, the difference between the aftereffects was significant. These findings should rule out the hypothesis that commonality of texture gradient is necessary to create an aftereffect.

Any texture gradient information present in the microtexture of the paper on which the line was viewed is ruled out as an explanation of the aftereffect, since no aftereffect was found when the line display was presented for monocular inspection.

GENERAL DISCUSSION

The present series of experiments has assumed a hierarchical feature detection model for the median plane slant aftereffect. In order to define the feature detectors mediating the effect, these experiments have investigated the slant cues that are necessary for the transfer of aftereffects. The results suggest that transfer of the slant aftereffect is mediated by a general mechanism which is not entirely specific to the slant cues which generate it.

Experiment 1 showed transfer across monocular and binocular viewing modes and across pictorial and binocular information. Experiment 2 showed transfer from linear to random texture. This finding could be explained by a texture gradient detection mechanism. However, Experiment 3 showed that the presence of a visible texture gradient is not required for transfer and that linear information is sufficient. These results are consistent with Kohler and Emery's (1947) suggestion that it is the appearance of slant rather than the specific cues resulting in that appearance that are essential for transfer of the slant aftereffect.

There is also evidence that transfer of aftereffects is greater when the display and the viewing condition in the test period are the same as those used during inspection. Moreover, Milewski and Yonas (1976) have shown that within a single viewing mode, changes in the spatial frequency of the surface texture between inspection and test reduces binocular aftereffect magnitudes. A hierarchical feature detection model has been applied to a variety of aftereffect phenomena (e.g., Coltheart, 1971), but considerable refinement is required in these theories to account adequately for the combination of specificity and generality found in the slant aftereffect.

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