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Texture Gradient Registration and the Development of Slant Perception

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Abstract

The processes underlying the development of slant perception were investigated by manipulating the degree of texture element variability. Subjects at four grade levels were required to make judgments of physical slant of surfaces with three levels of variability. Absolute error of judgment decreased with age, but texture variability had no effect at any grade level. The results suggest that there is no improvement in the ability to extract gradient information. Rather, improvement in the consistency of judgment reflects a developmental change in the relationship between stimulus information and judgment.

Texture Gradient Registration and the Development of Slant Perception

Since stimulus information available to an observer remains constant over age, developmental changes in perceptual ability must reflect age related changes in information utilization. Few attempts have been made, however, to assess the developmental changes in information utilization, perhaps because of the difficulty in specifying the information necessary for a particular task. This difficulty has been overcome in the area of space perception and specifically the perception of slant (defined as the inclination of a surface toward or away from an observer).

The informational basis for slant perception has been discussed by Purdy (1960), Flock (1965), and Rosinski (1974). Purdy, in a mathematical analysis, has demonstrated that for static, monocular arrays the relative rate of change of certain texture parameters (namely, the height, width, area, and spacing of elements) defines a texture gradient which potentially specifies surface slant. It has been shown that there is an invariant relationship between the information provided by. a texture gradient and physical slant. The gradient available at any point on the surface is directly related to the cotangent of the angle formed by the surface and the line of regard. Consequently, the gradients unambiguously specify absolute slant of the surface relative to any arbitrary reference axis.

As J. J. Gibson (1966) and E. J. Gibson (1969) have argued, there are two possible ways in which developmental improvements in information utilization may occur, given such an invariant relationship between texture gradient and physical slant. An individual's ability to differentiate a gradient may improve; that is, his ability to compare texture elements and extract the relative rate of change which defines a gradient may improve with age. As the ability to differentiate a gradient improves, perceptual judgment should improve.

Gibson (1969) argued that improvements in differentiation (i.e., in extracting information from stimulation) accompany perceptual development. However, improvement in differentiation is not sufficient to account for perceptual development. One must also pick up the relationship between these visual inputs and those of other perceptual systems and detect the multimodal invariant relationship among these sources of information. This extraction of invariant relationships is a crucial aspect of development, since potential information may not be effective if it is not related to physical layout: For example, a particular gradient may provide no information (may be meaningless) unless the relationship between that optical gradient and physical slant is established.

Such a conclusion is suggested by Rosinski and Levine (1976, in press). In studying the effectiveness of various texture gradients, they presented stimulus displays which provided either linear perspective gradient information or compression (foreshortening) gradient information. One must, in order to extract a linear perspective gradient, compare the relative width of texture elements along successive portions of the display. Although the minimal processing capabilities (estimation and comparison of angular extents) necessary for the differentiation of the two gradients are the same, differences in effectiveness were found. Perspective gradients provided a more effective basis for slant judgment than did compression gradients. These results suggest that the differential effectiveness of the two gradients may be due to differences in the degree to which each gradient had been associated with the physical slant it specified.

Although Purdy's (1960) analysis of texture gradient information assumed that each texture element had the same physical size, both Purdy and Flock have shown that this analysis applies to irregularly textured surfaces. If the size of texture elements varies over the surface, the gradient is defined as the rate of change in the average size of an element. That is, the gradient is the relative rate of change of the average size of a texture element across the display.

This extension of texture gradient theory to irregular surfaces has important implications. Since size averaging must be used, the differentiation of a gradient should be more difficult from irregular surfaces than from regular ones. However, since the gradient projected from regularly or irregularly textured surfaces both define a particular slant, judgments should, in principle, be equally accurate *once the gradient has been differentiated*. If perceptual improvement is the result of improved gradient extraction, children should have considerably more trouble than adults in judging the slant of irregularly textured surfaces. Children's performance with regular textures may be nearly as accurate as that of adults. Studies by Flock and Moscatelli (1964) indicate that adult subjects can differentiate a texture gradient in spite of variability in texture element size. Regularity of texture element size had no significant effect on the accuracy of slant judgments. These data suggest that adults are able to use texture gradients specifying slant in spite of size variability; that is, they are able to overcome the increased difficulty of differentiating the gradient.

The purpose of the present study was to explore developmental differences in slant perception; to determine the effect of texture element size variability; and to determine whether increasing the difficulty of differentiating a gradient would affect children's ability to judge slant. If perceptual development is related to changes in differentiation ability, texture variability and age should interact, with increased variability affecting younger subjects more than older ones. If development is not simply related to changes in differentiation, an age effect, but no variability effect, should be found. To test these predictions, we used surfaces like those found maximally effective by Rosinski and Levine, and manipulated difficulty of differentiation by varying texture element size.

Method

Subjects

Twenty-four subjects at each of four grade levels (first, mean age 6.4 years; third, mean age 8.4 years; fifth, mean age 10.3 years; and college student volunteers, mean age 19.3 years) served as subjects. At each grade level an equal number of males and females were tested. Subjects who normally wore corrective eyeglasses did so in the experiment.

Apparatus

In order to eliminate sources of information other than monocular texture gradients, the technique of polar projection shadow casting was used (see Figure 1). A 25 W concentrated arc lamp (arc size 1.2 mm) projected through a transparent generating surface onto a ground glass rear projection screen. The generating surface was constructed so as to hold textured surfaces at one of five slants (30, 40, 50, 60, or 70° from the vertical), with increasing slants indicating increasing distance of the top of the surface. In order to reduce the possibility of a rectilinear frame of reference for the subject, the screen was covered with a 13 in. (33 cm) circular aperture (visual field size equals 20.5°). The axis of rotation of the generating surface bisected the field of view which was completely filled with the projection of the generating surface at all slants. A chin stand assured that the subject was at the appropriate station point during the experiment. Subjects viewed the display monocularly.

Since the subject's head was not rigidly fixed, some amount of projective distortion was possible if the subject shifted his position. In the present experiment, the maximal possible displacement of the viewing point would introduce an optical magnification of 1.03, which would result in a maximal change in projected slant of less than 0.7°. The effects of such potential distortions, then, are negligible.

Various stimulus gradients were presented by placing a sheet of textured Plexiglas on the generating surface. Three textured surfaces were constructed using Tactype solid black squares No. 2043. Position of the texture elements was identical for the three textured surfaces. Each Plexiglas surface, 6 in. (15.24 cm) x 23 in. (58.42 cm) was partitioned into 552 1/2 in. (1.2 cm) cells. Two hundred forty-two square elements were randomly assigned to the cells with the restrictions that successive rows were staggered (to reduce linear perspective cues) and that no more than three consecutive elements or three consecutive spaces could appear in a single row. The mean element size on all three surfaces was 1/4 in. (0.64 cm). Surface 1 consisted only of 1/4 in. (0.64 cm) squares; surface 2 consisted of 1/8 in. (0.32 cm), 1/4 in. (0.64 cm), and 3/8 in. (0.95) squares; and surface 3 consisted of 1/16 in. (0.16 cm), 1/8 in. (0.32 cm), 1/4 in. (0.64 cm), 3/8 in. (0.95 cm), and 1/2 in. (1.27 cm) squares.

Procedure

Subjects were tested individually and were instructed to set the inclination of a palmboard to match the slant projected on the screen. Each subject was given four preliminary trials with full binocular viewing to assure that the instructions and procedure were understood. After these practice trials each subject made a total of 30 judgments, ten judgments of each surface in counterbalanced order (two randomized blocks of the five physical slants). Between trials, the screen was occluded while the physical slant was changed, in order to eliminate the optical transformations that accompanied adjustments of the generating surface. Subjects' judgments were recorded to the nearest degree.

Results

Several researchers have suggested that changes in error are important aspects of perceptual development (Gibson, 1969; Lambercier, 1946; Wohlwill, 1963). Gibson, for example, has shown that reductions in constant and variable error are characteristic of perceptual development. Since our main concerns were with developmental processes in perception and with accuracy of judgment, the first analysis involved absolute error, which provides a single index of both constant and variable error and is thus a measure of developmental change. Absolute error was analyzed in a 4 (grade) x 2 (sex) x 3 (texture variability) x 5 (slant) x 2 (block) analysis of variance with repeated measures on the last three factors. Figure 2 presents mean absolute error for each grade and level of texture variability.

There was a significant effect of grade on absolute error, $F(3, 88) = 7.57$, $p < .001$. Error decreased over grade level. A Newman-Keuls analysis showed significant differences in performance between Grades 1 and 3, 1 and 5, 1 and adult, 3 and adult, and 5 and adult (all ps < .01). It is apparent that over the range of ages tested there is a progressive improvement in slant perception based on texture gradient information.

No effect of texture size variability was found, $F(2, 176) = 2.93$, $p > .05$. Within the range of texture variability used in this study, subjects were apparently able to differentiate texture gradients regardless of element size variability. Neither constant nor variable error varied as a function of texture size variability. Likewise, no Grade x Texture variability interaction was observed, $F(6, 176) = .86$, $p > .10$. Younger subjects did not have correspondingly greater difficulty differentiating the irregular textures.

A significant main effect of physical slant was observed, $F(4, 352) = 21.59$, $p < .001$. Newman-Keuls analysis revealed that the mean absolute error of judgment was significantly larger for the slants of 30, 40, and 50° than for the 60 and 70° slants (all *p*s $< .01$). All other main effects and interactions were nonsignificant (*p*s $> .10$).

Recently, Poulton (1973) suggested that the use of within-subject designs in psychophysical experiments may be influenced by unwanted range effects. To ensure that such range effects did not contaminate our results, a separate between-subject analysis of variance was conducted using only the data from the first stimulus condition viewed by each subject (again using absolute errors). As in the previous analysis, the effects of grade, $F(3, 72) = 6.48$, $p < .001$, and physical slant, $F(4, 288) = 13.05$, $p < .001$, were significant. No other main effects or interactions were significant (all *p*s $> .10$). The congruence between these two analyses suggests that range effects did not influence our results.

In addition, a third analysis for position and carryover effects was conducted. This analysis indicated that there were no position effects, $F(2, 2866) = .25$, $p > .10$, and no carryover effects, $F(4, 2866) = .19$, $p > .10$.

The absolute error analysis demonstrated the existence of a developmental effect in this task. To further examine the locus of this effect, several additional analyses were conducted (see Table 1). The constant error of judgment varied little across grade, with adults averaging less than a degree better than the first graders. A randomization test for independent samples (Siegel, 1956, p. 152) showed no significant differences among grades, $t(14,38) = - .02$, $p > .10$. Therefore, the developmental effect discussed above is not the result of increased accuracy of judgment.

Variable error over the different grade levels, however, decreased significantly with age, Cochran's $C(4, 719) = .33$, $p < .01$. This pattern of results suggests that the developmental effect observed in the absolute error analysis is a result of a developmental improvement in the consistency of slant judgments rather than their accuracy. These results are also consistent with Gibson's findings that “variable error decreases steadily with age, and more consistently than does constant error” (1969, p. 375).

These conclusions were further supported when the slant judgments were evaluated in an analysis of variance, with the same five factors as in the absolute error analysis. There was no effect of grade on the judgments of slant, $F(3,88) = .15$, $p > .10$. Since an analysis of slant judgments is responsive only to changes in constant error, this result indicates that there was no change in constant error over grade. This suggests, in turn, that the observed grade effect in the absolute error analysis is a result of a change in variable error.

The main effect of sex was significant, $F(1, 88) = 7.46$, $p < .01$. Females tended to make more accurate slant judgments than did males. There was also a significant main effect of physical slant, $F(4, 352) = 321.00$, $p < .001$, indicating that there was a correspondence between physical and judged slant. All other main effects and interactions were nonsignificant (all *p*s > .10).

To provide a means of comparing our data with those of previous studies (see Flock, 1965), regression equations are presented in Table 2. Individual slopes were analyzed in a 4 (grade) x 3 (texture variability) analysis of variance (see McNemar, 1962, pp. 352-356). Although there is an apparent trend toward decreasing slopes over grade, this trend is nonsignificant, $F(3, 92) = .81$, $p > .10$. Similarly, there is no significant effect of texture variability on slopes, $F(2, 184) = 4.35$, $p > .01$.

Discussion

The finding that absolute error of judgment decreases with grade replicates and extends the previous findings of Rosinski and Levine. Our results show that even in the first grade, children are sensitive to the variables of texture gradient information, and are able to extract such information from surfaces covered with textures varying in element size. In the Rosinski and Levine study there was some suggestion that performance based on the multiple gradients does not improve over grade level. However, our results demonstrate absolute error of judgment decreased over grade, even though slant was specified by four redundant texture gradients. Although the correlation and regression analyses indicate a substantial correspondence between physical and judged slant at even the youngest age levels, our data also demonstrate the existence of further developmental change over age.

The analysis of actual slant judgments reveals that this developmental improvement is not a result of improved accuracy of slant judgments, since mean judgments did not differ. Rather, the data indicate that the developmental effect is a result of improved consistency of slant judgments, since the variability of slant judgments decreased over grade level.

The main effect of physical slant on judgments may be due to the relationship between texture gradients and slant. Although each gradient corresponds to a unique slant, the relationship is not a linear one. Rather, the gradients are proportional to the tangent of the optical slant. Consequently, the difference between two gradients is not equal to the difference between the two optical slants, but to the difference between the tangents of the slants. The difference between the gradients projected from 30 and 40° slants (from the vertical), then, is less than the difference in gradients projected from 60 and 70° slants. Our results indicate that gradients projected by the larger slants are more effective than smaller ones.

Purdy (1960) and Flock (1965) have argued that the extraction of gradient information from irregularly textured surfaces involves a size averaging mechanism. Inaccuracies in this averaging process could lead to increasing constant error (as a result of errors of size estimates) or increasing variable error (as a result of element sampling errors) with increasing element size variability. Neither of these effects were observed in the data. The processes which determine the effectiveness of gradient information seem to be little influenced by texture size variability. This conclusion is true at all grades; the gradients could still be differentiated with a high degree of accuracy at all age levels. These results and the absence of a grade by variability interaction suggest that the developmental improvement in judgment is not the simple result of an improvement in differentiation. Increasing the variability of texture element size had no differential effect over grade, either in terms of accuracy or consistency of judgment. Although improvements in differentiation may be important in the early development of this ability, they do not provide a sufficient explanation for the improvement observed in the present study.

As suggested earlier, the perception of spatial layout requires that visual input be related to other perceptual systems so that the invariant relationship between visual texture gradients and other sources of slant information can be extracted. Our results suggest that this process may have particular developmental characteristics. The fact that constant error did not decrease over grade suggests that even the youngest subjects were able to extract the appropriate gradient accurately. The grade-related decrease in variable error suggests that the developmental improvement involves a change in the consistency with which stimulus information is related to perceptual judgment.

In summary, the present study suggests that monocular slant perception based on texture gradient information comes into increasing correspondence with physical layout over development. Increasing the difficulty of differentiation by varying texture element size did not affect judgmental accuracy at any grade level. This pattern of results suggests that in addition to the process of gradient differentiation, a crucial aspect of perceptual development involves the invariant relationship between stimulus information and physical layout.

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Author Notes

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Table 1

Means and standard deviations of slant judgments for each grade-slant combination

	Slant (in degrees)				
Grade	30	40	50	60	70
1	$\bar{X}$ = 13.80 SD = 21.4	$\bar{X}$ = 19.82 SD = 28.1	$\bar{X}$ = 31.70 SD = 25.4	$\bar{X}$ = 50.76 SD = 30.4	$\bar{X}$ = 70.19 SD = 28.7
3	$\bar{X}$ = 13.63 SD = 22.4	$\bar{X}$ = 24.24 SD = 24.3	$\bar{X}$ = 37.46 SD = 25.1	$\bar{X}$ = 51.57 SD = 19.4	$\bar{X}$ = 67.75 SD = 20.7
5	$\bar{X}$ = 15.38 SD = 19.3	$\bar{X}$ = 26.94 SD = 23.9	$\bar{X}$ = 37.21 SD = 25.8	$\bar{X}$ = 51.91 SD = 21.1	$\bar{X}$ = 64.69 SD = 23.6
Adult	$\bar{X}$ = 15.25 SD = 19.8	$\bar{X}$ = 25.47 SD = 23.5	$\bar{X}$ = 34.69 SD = 14.3	$\bar{X}$ = 51.01 SD = 14.8	$\bar{X}$ = 63.12 SD = 13.5

Table 2

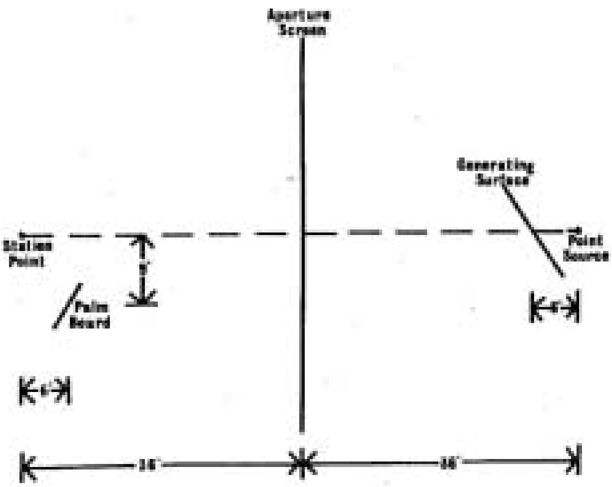
Regression equations of judgments (Y) for physical slants (X) as a function of grade and texture variability

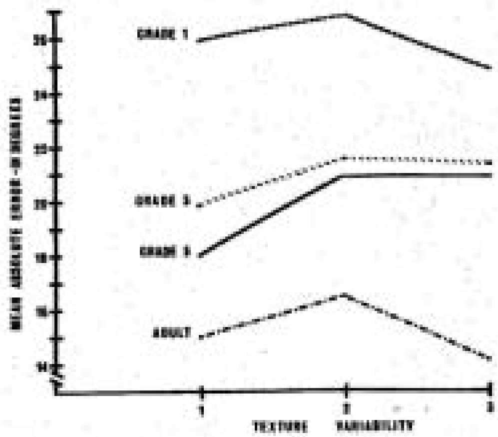
Grade	Texture variability level		
	Zero	Intermediate	Highest
1	Y = 1.49X − 39.86	Y = 1.54X − 41.43	Y = 1.23X − 41.43
3	Y = 1.38X − 28.51	Y = 1.50X − 37.16	Y = 1.22X − 22.32
5	Y = 1.19X − 19.50	Y = 1.28X − 26.46	Y = 1.27X − 22.67
Adult	Y = 1.06X − 13.97	Y = 1.29X − 28.00	Y = 1.29X − 24.40

Figure Captions

Figure 1. Schematic diagram of point source projection apparatus and viewing conditions.

Figure 2. Mean absolute error in judgment as a function of grade level and texture variability. Level 1 equals zero variability, level 2 equals moderate variability, level 3 equals high variability.


Aperture Screen
Generating Surface
Station Point
Point Source
Palm Board


GRADE 1
ADULT
1
2
3
TEXTURE VARIABILITY