Influence of Six Types of Visual Structure on Complexity Judgments in Children and Adults

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Individuals at five grade levels (kindergarten, Grade 2, Grade 4, Grade 6, and college) made pair-comparison judgments of visual complexity. The influence of the presence or absence of six types of visual structure (double symmetry, vertical symmetry, horizontal symmetry, diagonal symmetry, checkerboard organization, and rotational organization) and of amount of contour were examined. Two general developmental trends were revealed: First, the age at which visual structure initially affected complexity judgments varied with the type of structure, independent of amount of contour, within the range of contour values used. Second, there was a uniform increase in the effect of structure on complexity judgments between the fourth and sixth grades. These results are discussed in relation to possible mechanisms of visual pattern encoding and complexity judgment.

From the earliest days of psychological investigation, it has been recognized that understanding the nature of structure and organization in visual perception is central to explicating the way in which the elements of sensation become the objects of thought. Currently, a resurgence of interest in the investigation of structural variables in visual information processing reaffirms the attraction of these questions. This same intellectual framework has led psychologists to suggest that an individual's response to visual complexity might be used as an index of cognitive development (Brennan, Ames, & Moore, 1966; Kagan, 1970; Munsinger, Kessen, & Kessen, 1964; Thomas, 1966, 1969). Specifically, it has been argued that developmental changes in the maximally preferred level of visual complexity might reflect developmental changes in visual processing capacity (Munsinger & Kessen, 1964). However, this research is difficult to interpret: Different measures of preference generate different results (Berlyne, 1969); there is substantial variability both among adults (Dorfman & McKenna, 1966) and among children (Thomas, 1969); and, more fundamentally, complexity is given diverse objective, subjective, and intuitive definitions in this research.

The present study derives from an effort...
to achieve a better understanding of the structural variables in pattern perception, especially of the determinants of perceived pattern complexity (Chipman, 1977). Patterns vary both in quantity (i.e., number of elements, number of turns, or amount of contour) and in the degree to which constituent parts are organized. For adults, the complexity of patterns is affected by both factors; complexity varies systematically with pattern quantity in randomly generated patterns, but complexity is reduced by the introduction of organization (Attneave, 1957). Adults' judgments of pattern complexity are sensitive to many types of stimulus structure including symmetries, checkerboard organization, and rotations (Chipman, 1977). However, this research also demonstrated that different types of structure vary greatly in the magnitude of their effects on perceived complexity. Presumably, these differences in effect arise from as yet uninvestigated differences in the processing through which the structure is detected, analyzed, and evaluated in judgments.

At this stage of the larger investigations, a developmental study can serve multiple purposes. Improved understanding of the stimulus variables permits clarification of the questions that have been asked about perceptual development. Certainly, responsiveness to stimulus structure has the greatest appeal as an indicator of perceptual and cognitive capacity; it should be studied under experimental conditions that permit separation of the effects of pattern structure and pattern quantity. Furthermore, there are advantages in a developmental study interlocking with the adult studies of pattern perception. Finding developmental differences in the response to various types of structure would lend support to the hypothesis that these types of structure are subject to fundamentally different types of processing. Our current understanding of developmental change may also suggest hypotheses about the types of processing involved. Correspondingly, one might achieve a more differentiated view of the perceptual and/or cognitive progress that occurs during human development. Later, the results of adult studies of the processing of visual structure could be used to explicate the nature of observed developmental changes.

Past research concerning children's responsiveness to stimulus structure, reviewed more fully in an earlier article (Chipman & Mendelson, 1975), is fragmentary and equivocal in its implications. There have been only a few investigations of well-specified structural variables, and these exemplify the general inconclusiveness of the research. Using a pattern reproduction task, Paraskevopoulos (1968) found a developmental sequence: Symmetry around both the horizontal and vertical axes facilitated performance at an earlier age than vertical symmetry alone; in turn, vertical symmetry facilitated performance at an earlier age than horizontal symmetry. However, in a near replication of Paraskevopoulos' study using tachistoscopic presentation, Boswell (1976) reported that vertical, horizontal, and double symmetries all facilitated performance as early as 6 yr of age. The level of performance in these reproduction tasks was generally so poor that the authors' interpretations of the results as reflecting children's responsiveness to the overall structural characteristics of the patterns may not be justified.

Less demanding experimental tasks seem more suitable for the investigation of children's perceptual capacity. Because adults' judgments of pattern complexity have produced more clearly interpretable data than have the preference tasks so popular in research with children, we investigated the feasibility of obtaining complexity judgments from children. A preliminary study (Chipman & Mendelson, 1975) demonstrated the practicality of pair-comparison complexity judgment for use with children. Three groups of children (ages 4-5, 7-8, and 9-10 yr) and a group of adults made pair-comparison judgments of the complexity of a set of eight patterns. Highly structured patterns were contrasted with unstructured patterns across a range of pattern quantity. Even the youngest subjects showed no difficulty interpreting the instruction to select the simpler pattern in each pair.
Greater pattern quantity resulted in greater judged complexity for subjects of all ages.

Furthermore, the preliminary study revealed developmental differences in response to pattern structure. For all subjects, judgments were affected by the presence of structure in the two low-quantity patterns, but sensitivity to structure in the two high-quantity patterns was absent in the younger children and gradually increased with age. Because the structured patterns in the preliminary study represented a variety of types of structure, it was unclear whether unresponsiveness should be attributed to excessive pattern quantity or to the type of structure. However, this preliminary study did demonstrate both the feasibility of the experimental method and the likelihood of obtaining interesting developmental differences in the present, larger study.

Pair-comparison complexity judgment was again the experimental method. Obviously, there was interest in a direct, within-subject comparison of responses to different types of structure. Unfortunately, the number of judgments required for complete pair-comparison designs increases rapidly with the number of stimuli. Therefore, an incomplete pair-comparison design was used. In this design, unstructured patterns provided a standard of complexity (based on a large number of comparisons) that was used to measure the complexity of various types of structured patterns. The unstructured patterns approximate pure variation in pattern quantity, the most fundamental and undisputed determinant of pattern complexity. In pilot experimentation with adult subjects, the unstructured patterns had been shown to have approximately the maximum complexity level possible given their levels of pattern quantity: This defines unstructured.

Six types of structure were used in the present study: (a) Double symmetry (i.e., symmetry about both the horizontal and vertical axes) was used because it is the epitome of pattern organization. (b) Vertical and (c) horizontal symmetry were included because Paraskevopoulos’ (1968) results suggested that sensitivity to double symmetry may precede sensitivity to vertical symmetry that may, in turn, precede sensitivity to horizontal symmetry. (d) Diagonal symmetry was used, since sensitivity to it might be expected to develop after sensitivity to other symmetries, reflecting children’s general difficulty with diagonality (Olson, 1970). (e) Checkerboard organization was included because young children were insensitive to the structure of a high-contour checkerboard in a prior study (Chipman & Mendelson, 1975) and because checkerboards are commonly used to probe infants’ pattern perception (e.g., Fantz, Fagan, & Miranda, 1975; Karmel & Maisel, 1975). (f) Finally, rotational organization (i.e., each quadrant of the pattern is a 90° rotation of the adjacent quadrants) was included since, objectively, it provides a substantial information reduction, equivalent to simultaneous symmetry about two axes.

Method

Subjects

Five age groups participated in the study: (a) 41 kindergarteners (16 girls and 25 boys)—mean age: 5 yr 5 mo ± 3.2 mo; (b) 24 second graders (12 girls and 12 boys)—mean age: 7 yr 6 mo ± 4.1 mo; (c) 24 fourth graders (9 girls and 15 boys)—mean age: 9 yr 6 mo ± 7.7 mo; (d) 24 sixth graders (15 girls and 9 boys)—mean age: 11 yr 0 mo ± 7.7 mo; and (e) 36 college students (18 men and 18 women). The school children were recruited from the Mission Viejo Elementary School, a public school in suburban Denver. The mean achievement scores of the student population were approximately 6 mo above the national norm. The college students participated in fulfillment of a course option at the University of Denver.

Stimuli

The 38 patterns shown in Figure 1 were used. Each consisted of a 6 X 6 matrix of black and white squares in which 12 squares were black. Within each row of the figure are four or five exemplars of one type of organization: (a) unstructured, (b) double symmetry (vertical and horizontal), (c) vertical symmetry, (d) horizontal symmetry, (e) diagonal symmetry, (f) checkerboard organization, or (g) rotational organization. (The lowest-contour diagonal and the checkerboards are not perfectly structured because of constructional constraints on the class of patterns. The axes of the 6 X 6 matrix are considered to be the axes of symmetry of the patterns. None of the structured patterns were randomly generated; therefore, they may...
have a significant degree of partial structuring in addition to the major structural characteristics specified.)

The 38 stimulus patterns were all compared for relative complexity by means of an incomplete pair-comparison design. The incomplete design was composed of six small and nearly complete designs, one for each type of structure. That is, six subsets of stimuli were constructed from the total set of patterns. Each subset contained exemplars of a given type of structure and the corresponding contour-matched unstructured patterns. All possible pairs of the stimuli in a subset were constructed, although a few of the very distant pairs involving the lowest contour patterns were deleted to reduce the total number of pairs. The unstructured patterns linked the parts of the larger, incomplete design.

The pairs were presented on printed pages that were divided into eight boxes (5.0 cm × 8.5 cm) by heavy black lines. Two 1.75-cm-square patterns were presented side by side on a halftone ground in each box. Pairs of patterns were randomly arranged on the pages with two constraints: (a) The same pattern did not appear in adjacent boxes and (b) the typical adult responses, determined in pilot work, comprised a Gellerman left-right series. All of the pairs from each of the six subsets formed subbooklets of four pages; the subbooklets were combined into complete stimulus booklets with the order of subsets varied according to a Latin square design. Thus, each stimulus booklet contained 192 stimulus pairs. A cover page contained four instruction pairs comparing high-contour unstructured patterns with low-contour structured patterns.

Procedure

In all cases, the subjects were instructed to select (point to or circle) the simpler pattern in each pair. (The practice patterns on the cover page were used to ensure that subjects understood this instruction. As in our previous study [Chipman & Mendelson, 1975], all seemed to understand the task.) Subjects were then instructed to work through the booklet; they were told that it might be difficult to decide, that there was no right or wrong answer, that we wanted to know their opinion, and that they should choose a pattern even if they were unsure.

Children in the kindergarten group were individually tested by an experimenter to ensure that they provided a response for each stimulus pair. It was necessary to reduce the work load for these children, so each child provided judgments for only three types of organization (either the first or second half of a booklet). All other subjects were

![Figure 1. Patterns used in the pair-comparison task.](image-url)
tested in classroom groups, with each subject completing the entire set of judgments.

Results

Scaling of Judged Complexity

The set of responses to all stimulus pairs for each age group comprised a single, incomplete pair-comparison design with unequal numbers of comparisons for each pair. (To reduce the total number of judgments, the stimulus set was constructed so that most unstructured patterns were compared directly many times, whereas different types of structured patterns were not compared directly at all.) The response matrices were subjected to a standard pair-comparison scaling procedure, the minimum normit chi-square solution described by Bock and Jones (1968, pp. 124–132). The scaling was done under Thurstone’s Case V assumptions.

In pair-comparison scaling, the basic datum is the proportion of subjects in a group who choose a particular member of a pair of items. More disproportionate selections of one item over another are translated into larger differences in scale values for the two items. The unit of the scale is arbitrarily set to correspond to an 84% versus 16% selection. A least-squares fitting procedure is used to obtain scale values that predict actual response selections as closely as possible. (In the particular analysis used here, the contribution of each pair to the scaling was weighted according to the number of times that the pair was presented.) In addition to scale values, the procedure provides statistical tests (chi-square) of the goodness of fit of the data to the scaling model.

Figure 2 displays the complexity values obtained for three types of patterns (viz., unstructured, doubly symmetrical, and checkerboard) that provided the most interesting developmental contrasts. (The results for the other types of structure have been omitted to clarify the graphs, but data pertinent to them are presented later.) Contour values have been plotted on a natural log \( \ln \) scale. All of the types of patterns approximated the same linear increase in complexity with increasing \( \ln \) contour. Furthermore, the separation between structured and unstructured patterns was approximately constant across levels of contour for all types of structure except rotational organization; older subjects (Grade 6 and college) were sensitive to rotational organization at low levels of contour but were relatively insensitive to this type of structure at high levels of contour. Comments from adult subjects indicated that they failed to notice the presence of organization in high-contour rotational patterns. Younger children were relatively insensitive to rotational organization at all levels of contour.

Despite the regular relation of the results to the stimulus variables, there were statistically significant deviations from the scaling model for all age groups. These arose from the multidimensional determinants of perceived complexity. A detailed pair-by-pair examination of the deviations from goodness of fit revealed two major sources. Subjects showed sharper discriminations between two patterns of the same type (i.e., between two structured or two unstructured patterns) than the scale values would predict. In addition, individuals differed in their treatment of the structured patterns in the same way that the average performance of the age groups differed.

The remainder of the Results section is devoted to answering three specific experimental questions. First, we examined the influence of amount of contour on sensitivity to structure, using data totally independent of the scaling results. Then, we considered the effect of types of organization on complexity judgments at different ages. To do so, we treated scaling values as dependent measures in further analyses; although deviations from the scaling model probably introduced some measurement error, the deviations did not invalidate the legitimacy of these analyses. Finally, we explored individual differences in performance, again using data independent of the scaling results. These three questions are now dealt with in turn.
Influence of Pattern Quantity on Sensitivity to Structure

In a previous experiment (Chipman & Mendelson, 1975), it appeared that amount of contour regulated children's sensitivity to structure; therefore, we examined the present data for evidence of this effect. It was obvious from the initial scaling that an age group sensitive to a particular type of organization is generally sensitive to that organization at all levels of contour. Thus, the group data suggested that amount of contour does not regulate sensitivity to structure.

Figure 2. Complexity as a function of \( \ln \) contour for unstructured (U), doubly symmetrical (B), and checkerboard (K) patterns for each age group.
Six Types of Visual Structure

(with the exception of rotational organization that has already been mentioned). However, if such an effect were to exist, it might be transitory, that is, briefly evident during the acquisition of sensitivity to a particular type of organization. Then, one would expect a consistent pattern of responses to pairs that directly measure sensitivity to structure (i.e., pairs that contrast a structured pattern with a quantitatively matched unstructured one). If amount of contour does regulate appreciation of structure, pairs involving a low-contour structured pattern would be easier than those involving a high-contour structured pattern. Therefore, all of the pairs that directly measure sensitivity to structure were treated like test items and were scaled for difficulty using the method of minimum normit chi-square category scaling (cf. Bock & Jones, 1968; Torgerson, 1958). The analysis revealed no obvious relation between the scaled difficulty of a pair and the amount of contour in the structured pattern. Thus, the suggestion that amount of contour generally influences sensitivity to structure was not supported.

Influence of Types of Visual Structure

To examine the influence of pattern variables on scaled complexity, the results for each age group were subjected to an analysis of covariance (multiple-regression analysis). Complexity values were regressed simultaneously on \( \ln \) contour (the covariate) and on dichotomous variables representing the presence or absence of each type of structure. The regression weights obtained for each structure type are comparable to mean effects in an analysis of variance and represent the reduction in complexity due to the presence of that type of organization.

Table 1 presents the regression equations obtained for each age group; except for rotational organization, the regression weights are a highly accurate representation of the scaling results. Statistical significance of the regression weights is also shown. The effect of \( \ln \) contour on complexity was highly significant for all age groups. As specified in the table, other regression weights were also statistically significant, indicating that patterns containing a particular type of organization were less complex than the unstructured patterns for the age group. To facilitate comparisons among the structure types, the mean standard error of the regression weights for structure types is also given in the table. (The standard errors were essentially constant across structure types.) Note that these statistical results were based on the final scale values, and, thus, were obtained with an \( n \) of only 38, corresponding to the number of stimulus patterns.

Two general developmental trends in sensitivity to types of structure were evident from the regression coefficients in Table 1 and from the graphs in Figure 2. First, increasingly greater weight was attributed to structure with age. Thus, the regression weights for the structural variables increased relative to the regression weights for \( \ln \) contour. In the graphs, the separation between structured and unstructured patterns increased with age; structured patterns were judged comparable to unstructured patterns of lower and lower contour.

The second general trend was that the relative weighting of different types of structure changed with age. For the kindergarten group, the variable for checkerboard organization did not contribute significantly to the regression equation, whereas the variable for double symmetry did; for the two older groups, the regression weights for checkerboard organization and double symmetry were approximately equal. That is, checkerboards were considered to be nearly as complex as unstructured patterns by kinder-

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1 The patterns are serving as representatives of pattern variables; therefore, the number of patterns (38), not the number of subjects or observations, is the appropriate sample to consider. Statistically, the scale values in a complete pair-comparison design are equivalent to the average of a hypothetical number of observations equal to the number of subjects multiplied by the number of stimuli. In this case, the appropriate \( n \) would be between 240 and 360 for different age groups. Statistical tests based on this assumption, however, would be jeopardized by the deviations from the scaling model. Therefore, the scale values have been treated as single observations on the patterns, and subsequent analyses of these values do not rely on conformity to the scaling model.
Table 1

**Regression Equation of Complexity for Each Age Group**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Age group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K</td>
</tr>
<tr>
<td>Log&lt;sub&gt;6&lt;/sub&gt; contour</td>
<td>.57***</td>
</tr>
<tr>
<td>Double symmetry</td>
<td>-.37***</td>
</tr>
<tr>
<td>Vertical symmetry</td>
<td>-.30*</td>
</tr>
<tr>
<td>Horizontal symmetry</td>
<td>-.11</td>
</tr>
<tr>
<td>Diagonal symmetry</td>
<td>-.12</td>
</tr>
<tr>
<td>Checkerboard organization</td>
<td>-.12</td>
</tr>
<tr>
<td>Rotational organization</td>
<td>-.21</td>
</tr>
<tr>
<td>SE</td>
<td>.10</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.85</td>
</tr>
</tbody>
</table>

* \( p < .05; ** p < .01; *** p < .001. 

Table 1 shows the regression equation of complexity for each age group. The variables include Log<sub>6</sub> contour, Double symmetry, Vertical symmetry, Horizontal symmetry, Diagonal symmetry, Checkerboard organization, and Rotational organization. Each variable is associated with regression weights for different age groups, indicating the relative influence of structure on complexity judgments.

garteners, whereas doubly symmetrical patterns were judged to be simple; in contrast, checkerboards were judged to be as simple as, or simpler than, doubly symmetrical patterns by the Grade 6 and college groups.

Further analyses were used to generate more convenient and transparent illustrations of these developmental trends. Two methods were used to compare the relative influence of structure types on complexity judgments for different groups. Both methods enabled examination of the effect of structure while eliminating the influence of group differences on the general fineness of discrimination. Although such differences would influence performance in many experimental tasks, these differences are irrelevant to questions concerning relative sensitivity to various types of structure. The two methods treated contour variation as an objective measure of complexity in order to gauge the influence of the structural variables. The first method simply involved transforming the scale values to equate the effect of \( \ln \) contour across groups. The second method involved a calculation of the “information reduction” provided by structure and had the advantage of enabling group comparisons based on evidence internal to each age group’s judgments.

The first method used the regression analyses shown in Table 1. A constant was computed for each age group by forming the ratio of the adult group’s regression weight for \( \ln \) contour with that group’s regression weight for \( \ln \) contour. Then, the group’s regression weight for each type of organization was multiplied by the constant. Thus, the scale values and the mean effects represented by the regression weights were made comparable across ages.

Figure 3 displays the transformed mean effects of structure and makes several points evident. The kindergarten and Grade 2 groups were substantially different. The kindergarten group was sensitive to double and vertical symmetries but was not sensitive to horizontal and diagonal symmetries nor to checkerboard and rotational organizations (cf. statistical significance in Table 1). The Grade 2 group, however, was sensitive to all types of structure. Note the dramatic increase in sensitivity to diagonal and horizontal symmetries and to checkerboard organization. From Grade 2 to Grade 4, there was an apparent decrease in sensitivity to some types of structure. Note the dramatic increase in sensitivity to diagonal and horizontal symmetries and to checkerboard organization. From Grade 2 to Grade 4, there was an apparent decrease in sensitivity to some types of structure. Note the dramatic increase in sensitivity to diagonal and horizontal symmetries and to checkerboard organization. From Grade 2 to Grade 4, there was an apparent decrease in sensitivity to some types of structure. Note the dramatic increase in sensitivity to diagonal and horizontal symmetries and to checkerboard organization.

From Grade 2 to Grade 4, there was an apparent decrease in sensitivity to some types of structure. The reason for this is clarified in the analysis of individual differences that is presented later. But, a more impressive difference was observed between Grade 4 and Grade 6. Children in Grade 6 were more sensitive to all types of structure than were younger children; the Grade 6 group was nearly as sensitive to visual structure as the college group. Finally, note that the relative weights of structure types in the two older groups are different from the relative weights in the younger groups. The relative change between checkerboard organization...
and double symmetry was particularly interesting.

Because the preceding method of converting results to a common scale might seem questionable, another analysis was undertaken. In addition to its utility for comparing age groups, the second analysis had theoretical interest. Amount of contour (i.e., pattern quantity) was considered to be a measure of pattern information. Then, it was possible to determine to what degree pattern information, subjectively measured through complexity judgments, was reduced by the presence of structure (i.e., to determine how much unstructured contour was equal in complexity to a structured pattern). Because the complexity of both structured and unstructured patterns increases in parallel with increasing \( \ln \) contour, such a transformation was relatively straightforward. The contour values necessary to equate the complexity values for unstructured and structured patterns were computed mathematically with the following equations:

\[
\text{Complexity}_u = W_c (\ln \text{contour}_u) + C
\]

\[
\text{Complexity}_s = \frac{W_c (\ln \text{contour}_s)}{W_s + C},
\]

where subscripts \( u \) and \( s \) refer to unstructured and structured, respectively, \( W_c \) is the regression weight for \( \ln \) contour, and \( W_s \) is the absolute value of the regression weight for a given type of pattern structure (cf. Table 1). The amount of unstructured contour equal in complexity to a given amount of structured contour was computed by equating the expressions in Equations 1 and 2.

\[
\text{Contour}_u = \frac{\text{Contour}_s}{\ln^{-1} (W_s/W_c)}.
\]

That is, the presence of pattern structure is equivalent to reducing the amount of pattern contour by some multiplicative factor. Table 2 presents these factors for each type of organization for each age group. The factors are directly interpretable as subjective reductions in stimulus information. Thus, for the kindergarten group, doubly symmetrical patterns had approximately half (.52) of the amount of information of unstructured patterns with the same amount of contour.

This analysis generated estimates of the influence of pattern structure for each age group, estimates that were directly comparable across groups. The results were entirely consistent with the group differences in Figure 2, supporting the legitimacy of the first method of rescaling regression weights.

In addition, the information reduction factors are of theoretical interest. The kindergarten, Grade 2, and Grade 4 groups treated doubly symmetrical patterns as if such structured patterns had one half, not one quarter, of the information of their random equivalents. In contrast, the Grade 6 and college groups treated doubly symmetrical patterns as if they had approximately one third of their random equivalents. We later suggest that this may correspond to one quarter of

\[
\text{Figure 3. Adjusted complexity for unstructured patterns and six types of structured patterns for each age group.}
\]
Table 2
Information Reduction Factors for Each Age Group and Structure Type

<table>
<thead>
<tr>
<th>Structure type</th>
<th>Kindergarten</th>
<th>Grade 2</th>
<th>Grade 4</th>
<th>Grade 6</th>
<th>College</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double symmetry</td>
<td>0.52</td>
<td>0.51</td>
<td>0.53</td>
<td>0.32</td>
<td>0.31</td>
</tr>
<tr>
<td>Vertical symmetry</td>
<td>0.59</td>
<td>0.59</td>
<td>0.54</td>
<td>0.38</td>
<td>0.33</td>
</tr>
<tr>
<td>Horizontal symmetry</td>
<td>0.82</td>
<td>0.54</td>
<td>0.62</td>
<td>0.42</td>
<td>0.34</td>
</tr>
<tr>
<td>Diagonal symmetry</td>
<td>0.81</td>
<td>0.61</td>
<td>0.79</td>
<td>0.38</td>
<td>0.34</td>
</tr>
<tr>
<td>Checkerboard organization</td>
<td>0.81</td>
<td>0.53</td>
<td>0.60</td>
<td>0.32</td>
<td>0.27</td>
</tr>
<tr>
<td>Rotational organization</td>
<td>0.69</td>
<td>0.75</td>
<td>0.72</td>
<td>0.51</td>
<td>0.48</td>
</tr>
</tbody>
</table>

the information of a random pattern with equal contour plus some additional information specifying the structure.

**Individual Performance**

There are at least two reasons for an analysis of individual performance in this experimental task. The complexity values obtained for each group amount to averages across individuals. In a developmental study, it is important to determine if group means accurately represent individual performance or if they reflect the averaging of discrete patterns that vary in frequency with age. Furthermore, if group means represent individual behavior, it is valuable to ascertain the variability of performance within a group.

There were insufficient data to produce a complexity scale for each individual. However, the weight attributed to visual organization by a subject was reflected in the individual's judgments for pairs that contrasted a structured pattern with those unstructured patterns of equal or lower contour. In all, 64 such pairs were presented to the four oldest groups. (The kindergarten group was not included in this analysis because each kindergartener responded to only half of the critical pairs.) The total number of cases in which an individual judged the structured pattern as simpler (the structure score) was considered an index of the individual's sensitivity to visual organization.

Table 3 presents the means and standard deviations and Figure 4 illustrates the distribution of the structure scores for each age group. There were at least two distinct distributions of structure scores: One corresponded to performance of the Grade 2 and Grade 4 groups, and the other corresponded to the majority of the Grade 6 and college groups. The distributions of the Grade 2, Grade 4, and Grade 6 groups did not appear to be multimodal; thus, group averages represented individual performance in these groups. (Note that the sample of second graders, unlike the fourth graders, contained a few high-scoring individuals; this undoubtedly explains the discrepancies in the developmental trends of the group results.)

In contrast, the adult data appeared to be bimodal or even trimodal. The structure scores of the majority of adults were distributed at the level of the Grade 6 scores. A small portion of the adults exhibited perfect or near-perfect scores, suggesting "categorical" treatment of structured patterns. Finally, a small portion of the adults' scores was

2 Despite the evident developmental progression in the overall results, there were certainly large individual differences in the responses of subjects of the same age. We have evidence to suggest that these individual differences are not random but show the expected relation to socioeconomic variables. A small number of subjects from a town in rural Michigan participated in the same experimental task. The mean structure scores of these individuals were: Grade 2 (mean age: 8 yr 2 mo) —31.0; Grade 3 (9 yr 3 mo)—30.8; and Grade 5 (11 yr 2 mo)—36.5. The scaled results of the two younger groups were similar to those of the kindergarten group reported here except that the Michigan groups discriminated more finely among contour values. Thus, there was almost a 2-yr difference in the developmental status of children from suburban Denver and from rural Michigan with respect to the experimental task.
distributed at the level of the Grade 2 and Grade 4 scores. This finding replicates a result in a previous study in which a small group of adults also gave childlike responses (Chipman & Mendelson, 1975).

### Discussion

This experiment constituted a massive confirmation of our prior finding that the development of sensitivity to visual structure, as indexed by complexity judgments, continues well into school age (Chipman & Mendelson, 1975). Two different developmental changes were observed in the present study. First, the age at which visual structure initially affected complexity judgments varied with the type of structure; generally speaking, the presence or absence of a particular type of organization influenced judged complexity independent of the amount of contour. Sensitivity to double symmetry and vertical symmetry appeared quite early, whereas sensitivity to horizontal symmetry, diagonal symmetry, and checkerboard organization appeared considerably later. Sensitivity to rotational organization, a structure type that provides more information reduction than the single-axis symmetries, was not fully evident even in the oldest subjects. These findings indicate that the type of visual structure, rather than a simple informational measure, is a critical factor accounting for age-related differences in sensitivity to visual organization. A second major developmental change in complexity judgments was observed between the Grade 4 group and the older (Grade 6 and college) groups. Individuals in the older groups attributed much greater weight to all types of structure in determining their complexity judgments.

### Relation to Previous Findings

Before turning to the interpretation of these results, their relation to other experimental findings should be considered. There have been two relevant developmental studies of pattern reproduction. Paraskevopoulos (1968) had children reproduce doubly symmetrical, vertically symmetrical, horizontally symmetrical, and asymmetrical patterns. He reported that double symmetry facilitated performance first at 6 yr of age, vertical symmetry first at 7–9 yr, and horizontal symmetry not until 11 yr. A replication of this experiment by Boswell (1976) suggested that the performance of even 6-yr-old children is facilitated by all three types of symmetry. The interpretations of both these experiments are threatened by the excessive difficulty of the experimental task: Boswell's 6-yr-old subjects reproduced less than 2.5 dots of vertically and horizontally symmetrical patterns and approximately 3 dots of doubly symmetrical patterns. In an unpublished analysis of adults' reproductions of Garner patterns, the total number of correctly reproduced dots was found to be very weakly related to the structural characteristics of the patterns, whereas the number of entirely correct reproductions was very strongly related to the structural characteristics. Thus, these reproduction experiments provide very weak evidence about children's capacity to respond to the structural char-
acteristics of patterns because it is likely that performance was governed by other correlated differences in stimulus characteristics. Nevertheless, these earlier experiments concur with the present study in the ordering of effectiveness of the three structure types: Double symmetry prior to or more effective than vertical symmetry, vertical symmetry prior to or more effective than horizontal symmetry.

The results for diagonal symmetry also accord with previous research. Sensitivity to diagonal symmetry first appeared in the Grade 2 group. This is consistent with findings that until 7 yr of age, children do not draw an acceptable diamond (Maccoby & Bee, 1965; Olson, 1968) and have difficulty discriminating (Rudel & Teuber, 1963) or remembering (Bryant, 1974) oblique lines.

In general, the developmental order of emergence of sensitivity to structure types is in agreement with the degree of effectiveness that these types of structure have as determinants of perceived complexity for adults (Chipman, 1977). Checkerboards are an apparent exception to this rule; this exception will be discussed in detail later. In one way, however, these patterns are not an exception because the opponent-color relations that make up checkerboards were found to be very ineffective in reducing perceived complexity when the amount of objective information reduction was equated, as it was not for the checkerboards in the present experiment. Consequently, it seems plausible that both developmental changes and differences in the effectiveness of pattern variables for adult perceivers will prove comprehensible within the same theoretical framework.

**Interpretation and Prediction**

To interpret these findings and to predict the results that might be expected in other experimental tasks, it is necessary to sketch a hypothetical account of the processes involved in complexity judgment. Complexity judgments probably derive from the perceptual encoding of the pattern in a simple manner. The *structural description*, in which pattern elements and their relations are specified, seems most attractive as a model for pattern encoding. Then, if a pattern contains a type of structure that halves the number of elements to be encoded, judged complexity of the pattern might equal that of an unstructured pattern with half of the number of elements plus a small increment attributable to the specification of the pattern structure. Adults' judgments of the complexity of structured patterns do display the requisite simple, systematic variation with pattern quantity (Chipman, 1977).

This hypothetical account yields several ways in which developmental changes may occur in complexity judgments. First, at a young age, certain structural features may not be registered at any level of perceptual processing, perhaps because of the nature of the perceptual processing required to detect those features. Second, even if structural features are registered at some level, they may not necessarily be incorporated in the encodings or representations that are the basis for complexity judgments. Finally, there may be developmental changes in the way complexity judgments are derived from encoded representations.

The developmental changes observed in the present study can be interpreted in light of this framework. The first developmental change that requires explanation is the emergence of sensitivity to different types of visual organization at different ages. The initial emergence of sensitivity to a structure type presumably represents a change in the ability to encode that type of organization. Because this change occurs at different ages for different types of structure, the emergence of sensitivity is not attributable to a change in the judgment process itself; changes in the judgmental process would affect all judgments at the same time. In particular, young children's performance is not attributable to superficial misunderstanding of the task. The fact that young children's judgments show the expected systematic relation with amount of contour is one form of evidence that they understand the task. Furthermore, since kindergarteners understand the term *simple* to mean doubly symmetrical and vertically symmetrical, we
know that they are not misunderstanding the task instruction as applying to quantitative variation only. There must be more profound reasons for their neglect of the other structural features, horizontal and diagonal symmetry and checkerboard organization.

Nevertheless, it is unclear whether insensitivity to a particular type of structure is due to a failure to register the structural information at all or to a failure to use the structural information in the judgment task. Possibly, it cannot be usefully incorporated in the encoding of the pattern. More evidence is necessary to distinguish these alternatives. If insensitivity to a given type of structure were evident in a wide variety of tasks, one might assume that the structural information is not registered. However, if sensitivity is demonstrable in even a single situation, one might assume that the information is registered but is not accessible for all tasks. It seems likely that certain types of organization (e.g., basic symmetries) may be registered very early indeed but simply may not affect complexity judgments at young ages. If further developmental evidence confirms the suggestion that a type of structural information is not being registered at all, this would have implications concerning the type of processing that underlies its detection. For example, some types of structure, such as rotational organization, may require a deliberative, cognitive analysis.

The second developmental change that requires interpretation is the general decrease in complexity judgments from the fourth grade to the sixth grade. Because the change occurred uniformly for all types of structure, it is reasonably attributed to a change in the judgmental process. One possible source of such change is suggested by the fact that the age at which this change occurred coincides with the transition to the Piagetian stage of formal operations. Thus, the increased influence of pattern structure might reflect the individual's awareness of the rule-governed nature of pattern descriptions; this would be one aspect of the emerging capacity to reflect on one's own mental processes and representations. However, if so, one would expect judgments of structured patterns to be categorical, which was by no means true for the majority of older subjects.

Another possible explanation of the change at sixth grade is worth considering. The difference between sixth graders and younger children may reflect qualitative changes in the encoding of structural information that affect perceptual encodings of nearly all visual stimuli. Some aspects of the results are consistent with this hypothesis. Information reduction attributable to structure was not greater than .5 prior to the sixth grade, even for double symmetry. After sixth grade, checkerboards were judged to be the simplest of all patterns, which corresponds to the information reduction provided by their embedded structural description; also, judgments of doubly symmetrical patterns approximated the objective information reduction of their structural description. Exploration of these possibilities may yield more general insights into the way that such patterns are encoded.

In discussing these results, we have arrived at a more differentiated set of hypotheses about what might be occurring in perceptual development. It has become clear that no one experimental task can suffice to measure children's perceptual capacities. Because perception is not a single, simple process, we cannot rely on any one probe to reveal the nature of developmental change. Instead, the study of perceptual development should be placed in the context of more general efforts to analyze and describe perceptual processes. It can contribute some information to that effort: Evidence that certain processes and phenomena do differ in significant ways.

Finally, there is parallel evidence that the perception of structure in realistic stimuli such as faces (Diamond & Carey, 1977) and drawings of scenes (Hock, Romanski, Galle, & Williams, 1978) also develops during school age. This suggests that explanation of the developmental changes observed in the perception of these abstract patterns will have more general significance for the understanding of perceptual development. Such comparable developmental changes in the perception of abstract and realistic stimuli
are reassuring with regard to the general strategy of using such simplified and well-specified stimuli in the study of perception.

References


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