Development of Visual Organization: The Perception of Subjective Contours

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Bertenthal, Bennett I.; Campos, Joseph J.; and Haith, Marshall M. *Development of Visual Organization: The Perception of Subjective Contours*. Child Development, 1980, 51, 1072–1080. This study examines the development of infants’ sensitivity to the organization of a subjective-contour stimulus array. 5- and 7-month-olds were sequentially shown 3 stimulus arrays of elements, only 1 of which was capable of producing subjective contours. Only the orientational relations among elements was varied. An infant habituation control procedure was used to test infants’ abilities to discriminate these arrays. The results indicated that (1) only 7-month-olds showed consistent differential responsiveness to changes from an illusionary array to a nonillusory array or vice versa, (2) 5-month-olds showed a weaker tendency to respond similarly and only when they had prolonged experience with the illusionary array, and (3) neither age group showed much response recovery to a change from one nonillusory array to another. These findings are interpreted as indicating that infants can perceive subjective contours. However, the age of this accomplishment probably varies with both the characteristics of the array and the abilities of the observer.

The process by which the infant organizes the elements of his visual field into objects remains a mystery. One approach to this problem involves assessment of developmental changes in sensitivity to configuration. Although interest in this question seems widespread (for reviews see Cohen, DeLoache, & Strauss [1979]; Cohen & Salapatek [1975]; Haith & Campos [1977]), few firm statements about the early development of configurational sensitivity are possible.

A major difficulty in several studies is that the claimed discrimination of configurations may actually be based on featural differences or on relations of feature subsets rather than on differences in the configuration of all the elements (Cohen et al. 1979; Haith & Campos 1977). This difficulty is particularly evident in two popular approaches. The most prevalent uses face stimuli (e.g., Caron, Caron, Caldwell, & Weiss 1973; Haaf & Bell 1967). The consensus from this literature is that infants can make certain types of facial discriminations by 5 months of age. However, because so many relations among subsets of features in these stimuli exist, it is extremely difficult to establish when perception of the face gestalt takes place (Ruff 1978).

A second approach involves the use of different stimulus arrays that are composed of multiple instances of the same element (Cornell 1975; Fantz & Nevis 1967; Salapatek 1975; Vurpillot, Ruel, & Castrec 1977; Welch 1974). The objective here is to produce perceptual arrays that differ only in the arrangement of their elements, so that any discrimination between arrays can be interpreted as evidence of configurational responding. In most of these studies, however, the orientation of the individual elements differs between configurations so that discrimination based on only parts of

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the stimuli is possible (Cohen et al. 1979; Haith & Campos 1977).

Recently, Vurpillot et al. (1977) reported a study that avoided this problem. After infants were familiarized to a configuration of elements that formed a cross, they were shown either a new configuration or the same configuration composed of different elements. Unlike previous studies, the orientation of each element remained constant in the new configuration. The results indicated that 2- and 4-month-olds responded to the new configuration but only when the individual elements were small and formed a regular arrangement. Even in this study, however, the change in configuration was confounded with a change in spatial distribution of elements. A similar problem was also present in a recent study by Milewski (1979). Thus, the issue involving babies’ discrimination of the differences in relations among elements has remained unresolved.

We hypothesized that a visual illusion produced by subjective contours (Schumann 1904) would be useful for studying the issue of whole form perception. An example of this illusion is presented in figure 1a. When presented with a stimulus producing subjective contours, most observers report seeing a “phenomenally complete object of uniform appearance, and delineated by subjective edges” (Dumais & Bradley 1976, p. 339). In reality, however, these perceptions have no physical correlates since the surface bounded by the subjective contours is actually identical to its background in brightness and color.

These stimuli possess a number of useful characteristics. First, the illusion is perceived only when all the elements are organized together in a particular way; even a minor alteration in the alignment of any one of the inducing elements can destroy this effect. Thus gross changes in placement, symmetry, or complexity need not enter into a test for discrimination between configured and nonconfigured arrays. Second, these stimuli permit easy variation of some of the parameters that must affect perception of configuration—for example, size and distance of elements and contrast ratio of elements to background. Finally, the illusion is not perceived immediately by the naive observer. A short amount of time is needed to organize the corners of the figure before the illusion is perceived, suggesting that the perception of this type of configuration is more complex than the perception of many other configurations, such as completely enclosed figures. With the possible exception of random dot stereograms (Fox, Aslin, Shea, & Dumais 1980), no other stimulus investigated in the infant literature shares this particular characteristic.

Pretesting suggested that infants might be capable of perceiving a subjective-contour stimulus array as early as 5–7 months of age. Theoretical considerations also suggested that this age range might be of interest. According to Piaget (1937/1954), 5–7 months of age corresponds to the period during which the infant begins to construct different planes of depth, a perceptual skill that may underlie the awareness of subjective contours (Coren 1972). Also, it is at this same age that the infant begins to be able to reconstruct a partially invisible whole from its visible parts (Piaget 1937/1954). Some theorists (e.g., Gregory 1972) hypothesize that an analogous process of reconstruction may be necessary for perceiving subjective contours, since only the corner elements are physically present.

In order to establish whether 5- and 7-month-old infants could perceive subjective contours in stimulus arrays, we designed a study in which each infant was presented with

![Fig. 1.—Examples of stimuli generating subjective-contour perception (I) or not (NI₁ and NI₂)](image-url)

one of two sets of conditions. (a) Illusion/non-illusion (or vice versa): This condition involved a discrimination between a subjective-contour stimulus array (fig. 1a) and a second stimulus array (fig. 1b or 1c), in which the illusion of the square was not possible because two or four of the elements were rotated 180°. Thus, there are three differences between the two displays: the presence or absence of the arrangement required for the illusion, the orientation of specific elements, and the symmetrical arrangement of the elements. (b) Two different non-illusion stimuli: This condition involved a test for discrimination between the nonillusion display of figure 1b and that of figure 1c. In contrast to the first pair, these two stimuli do not differ in regard to the presence or absence of the illusion arrangement. However, as in the first pair, the second pair differed in symmetry and element orientation.

By comparing infants’ discrimination of the arrays in these conditions, we could determine whether the illusion arrangement yielded a unique response. If infants did not perceive the subjective contours, both pairs of stimuli would be discriminated equally since the remaining differences between the pairs were the same. However, if infants did perceive the subjective contours, greater discrimination would be possible between the pair involving the illusory change since this pair contained more detectable differences than the preceding pair.

Method

Subjects.—The final sample consisted of 72 (34 male, 38 female) healthy, full-term infants from middle-class families. Half were 5 months of age (mean = 20 weeks, 3 days) and half were 7 months of age (mean = 30 weeks, 5 days). An additional 31 infants were tested but not used because of problems with state (16), lack of interest in the stimuli (six), equipment failure (five), or failure to habituate (four). The infants were recruited from a pool of children who were volunteered by their parents to participate in studies conducted in the developmental laboratories at the University of Denver. The parents were paid $2.00 for their infant’s participation in the study.

Stimuli.—Three different slides were used as stimuli. Each slide was composed of four identical blue elements on a yellow background. As can be observed in figure 1, each element was circular in shape with one quadrant removed. When projected, the elements measured 5.08 cm (1.74° of visual angle) in diameter and the center of each element was situated 11.43 cm (3.9° of visual angle) from each adjacent element center. These elements maintained the same relation to the visual frame in each stimulus.

The three stimuli (see fig. 1) differed in one important way. In the first stimulus, henceforth referred to as the illusion (I), the elements were arranged to project the illusion of a bright yellow square on a yellow background. The illusion measured 13.97 cm per side (4.76° of visual angle). The second stimulus—nonillusion 1 (NI1)—did not produce the illusion of a square because two of the elements were rotated 180° around their planar axes. Similarly, the third stimulus—nonillusion 2 (NI2)—did not produce the illusion because all four elements were rotated 180° around their planar axes.

Design.—An infant habituation control procedure (Cohen 1972; Horowitz, Padon, Bhana, & Self 1972) was chosen to assess the extent to which each stimulus pair could be discriminated. In this procedure, one stimulus is repeatedly presented until looking declines to some relative criterion. After criterion is reached, a novel stimulus is presented on the next few trials. The amount of response recovery displayed to the novel stimulus indicates the degree to which the novel and previously presented stimulus are discriminated.

Infants at each age were randomly assigned to one of three groups. Each group began the experiment with the presentation of a warm-up slide for two trials. Immediately following this slide, the three experimental stimuli were presented in three different orders. In group 1-NI1, infants were habituated to the illusion stimulus and were then presented with nonillusion stimulus 1 for two trials followed by nonillusion stimulus 2 for two trials. In group NI1-NI2, infants were habituated to nonillusion stimulus 1 and were then presented with nonillusion stimulus 2 for two trials followed by the illusion stimulus for two trials. In group NI2-I1, infants were habituated to nonillusion stimulus 2 and were then presented with the illusion stimulus for two trials followed by nonillusion stimulus 1 for two trials.

Two additional trials of the familiar stimulus (lag trials) were presented after criterion had been reached to a random half of the infants in each group (lag controls). The lag manipulation permitted an assessment of the
contribution of spontaneous regression to the infants' recovery scores to the novel stimuli.

Apparatus and materials.—The apparatus used for testing the infants (see fig. 2) was composed of two cubical open-ended wooden chambers that were oriented perpendicularly to each other. A large wooden hood extended out from the intersection of these two chambers in order to restrict the viewing area of the infant who was seated inside of this hood. The infant's viewing area was illuminated by a fluorescent light hung from above. A light diffusing plastic at the top of the cubicule assured even ambient illumination averaging 8.75 footlamberts. Both chambers and the space enclosed by the hood were lined with black felt.

The infant sat on the mother's lap and faced a 50/50 mirror (measuring 40.6 x 30.5 cm) situated at the intersection of the two chambers. The mirror was mounted at a 45° angle to the infant's line of sight. Positioned behind the mirror in chamber 1 was a low-light video camera (Sony AVC-3250) with a zoom lens (12.5–75 mm). The camera was mounted on an adjustable tripod. During the experiment an assistant operated the camera so that a relatively large and focused image of the infant's eye could be kept in the camera's field of view. This image was recorded on a video recorder (Sony AV-3600) and simultaneously displayed on a television monitor (Sony CVM-950) in an adjacent control room.

A slide projector (Sawyer's Rotomatic 737AQ) was also located in the control room and projected the stimuli through a glass window onto a rearview projection screen (measuring 60.96 x 60.96 cm). The screen was located at the end of chamber 2, 76.2 cm from the center of the mirror. The infant was located approximately 91 cm from the center of the mirror.

A Beckman two-channel-type RS Dynograph located in the control room recorded heart rate and the electrocardiograph by way of three Beckman miniature biopotential electrodes in a chest configuration. ¹

All on-line computations were accomplished with a programmable calculator (HP-67) also located in the control room. This calculator was used for computing and recording the duration of each trial, and it also indicated in the LED display when the criterion response level had been attained (see Haith & Bertenthal [1979] for a more detailed description). The calculator sat in a small cradle and was triggered by a long actuating bar that also

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¹ The heart-rate data were collected for another purpose and will not be discussed any further in this report.
activated two microswitches. One microswitch sent a pulse to the event pen on the polygraph and the other sent a pulse to the digital logic, which in turn controlled the projection of the slides through activation of a Lafayette Instrument Co. (#43016) T-scope shutter. During the time that the shutter was closed and the screen was dark, a tone was transmitted to the video recorder so that this period could be identified on the videotape.

Procedure.—The infant was seated on the mother’s lap underneath the hood and oriented so that he or she faced the mirror where the stimuli would be projected. Although the infant was positioned so that he or she had a complete view of the stimulus, the mother’s view of the top half of the stimulus was obstructed by the design of the apparatus. The mother was instructed not to talk to her infant or to try to look at the slides during the study.

As soon as the infant appeared comfortable, the slide projector was turned on and the first slide was presented. An observer who was able to look at the infant’s eye on the monitor in the control room pressed the calculator actuating bar at the beginning of the trial as soon as the infant maintained a fixation on the stimulus for .5 sec. The trial was terminated by a second press on the actuating base when the infant looked away from the stimulus for more than .5 sec. Judgments concerning when the infant was looking at the stimulus were based on whether the corneal reflection of the light above the hood was directly above the center of the pupil. As soon as the trial ended, the T-scope shutter attached to the slide projector was automatically activated and the screen became dark for 7 sec. At the end of this interval, the shutter was automatically opened and the next trial was initiated as soon as the infant began looking at the stimulus again.

A relative habituation criterion for each subject consisted of the total looking on three consecutive trials that summed to no more than 50% of the total looking on the first three trials. In cases (N = 31) where the total fixation for the first three trials was less than 12 sec, an absolute habituation criterion was used. When this criterion was employed, habituation in this condition was defined as a total of 6 sec or less looking time on three consecutive trials.

After criterion was indicated on the calculator, the first novel stimulus was presented for two trials, and then the second novel stimulus appeared for two more trials. For infants in the lag condition, the presentation of the first novel stimulus was delayed until two trials after criterion had been reached.

Reliability.—The first observer scored the infants’ visual fixations during the course of the experiment but remained blind to the specific conditions being tested.

After all the infants had been tested, 14 were randomly selected and rescoped from the videotape by the second observer. To eliminate extraneous cues to trial offset, the tone recorded on the videotape for indicating the interstimulus interval was eliminated in reliability assessments. The correlation coefficient computed between these scores of the two observers was \( r(12) = .96 \). The mean difference between the two scorers was .49 sec.

Results

The most important finding was that, for 7-month-olds, greater response recovery occurred when an illusory versus nonillusory stimulus change occurred than when both the familiar and new stimuli were nonillusory. The younger group showed similar differential recovery only for the illusory-to-nonillusory sequence. Furthermore, the differential recovery appeared only for the first stimulus change.

Response recovery to the first novel stimulus.—The first analysis compared response recovery on the last two habituation trials and the first two postcriterion trials for babies who saw a novel stimulus (nonlag) and babies who saw the familiar stimulus (lag) on the postcriterion trials. By comparing the performance of lag and nonlag infants, spontaneous regression was controlled. The design of this analysis involved four factors: age (5 or 7 months), group (I-NI\(_1\), NI\(_1\)-NI\(_2\), NI\(_2\)-I), condition (novel or familiar stimulus on first two postcriterion trials), and trials (last two habituation or first two postcriterion trials). Age, group, and lag were between-subjects variables, and trials was a within-subjects variable. The dependent measure in the present and all subsequent analyses was mean duration of looking per trial.

Prior to testing infants, five adults assumed the infant’s position in the apparatus and reported when they were looking at the stimulus. From these reports, the location of the corneal reflection of the marker light that indicated fixation of the stimulus was determined.
Individual comparisons (Kirk 1968) were conducted at each age × group condition to determine which groups showed a significant amount of recovery to the novel stimulus (see fig. 3). At 7 months of age, infants in both groups receiving an illusory change (I-NI1 and NI2-I) showed a significantly greater amount of response recovery than did the lag infants in these same two groups, \( t(60) = 2.42, p < .02 \), and \( t(60) = 3.38, p < .005 \), for groups I-NI1 and NI2-I, respectively. At 5 months of age, only group I-NI1 showed a significant amount of response recovery after the lag re-

![Graph showing mean duration of looking per trial in seconds for 5-month-olds and 7-month-olds.](image)

**Fig. 3**—Mean looking duration on last two habituation and first two postcriterion trials (PC) for subjects who continued to receive the training stimulus (lag group) and those receiving the test stimulus (nonlag group).

In order to ascertain whether the response recovery to the illusory change was significantly greater than the recovery to the nonillusory changes, the recovery scores of I-NI1 and NI2-I were pooled and compared directly against the recovery scores of NI1-NI2. Planned comparisons indicated that the predicted pattern of results was significant at 7 months, \( t(60) = 2.45, p < .02 \), but not at 5 months. A comparison that involved only the recovery scores of I-NI1 and NI1-NI2 at 5 months of age was also conducted, and this analysis revealed a nonsignificant trend in the expected direction, \( t(60) = 1.28, p < .15 \). Thus, even though 5-month-olds in group I-NI1 showed significant response recovery, the difference between this group and group NI1-NI2 was neither as large nor as stable as at 7 months of age.

The first analysis used only half the infants in each group to test discrimination of the two stimuli. A second analysis was performed that employed the response-recovery data for all subjects by using the same recovery scores of the lag groups as used in analysis 1 and by using statistically estimated lag scores for the nonlag group.\(^3\)

The results were very similar to those of the first analysis (see fig. 4). Only 7-month-olds showed a significant amount of recovery to the illusory change, \( t(66) = 2.89, p < .01 \), and \( t(66) = 4.26, p < .001 \), for groups I-NI1 and NI2-I, respectively, and this recovery was significantly greater than the recovery shown by the group receiving only the nonillusory change (NI1-NI2), \( t(66) = 1.81, p < .10 \). Between-age comparisons of response-recovery scores revealed highly significant age differences for groups NI2-I, \( t(66) = 2.39, p < .02 \), and for groups I-NI2 and NI2-I pooled together, \( t(66) = 2.00, p < .05 \). Comparison of groups I-NI1 at the two ages was not significant.

Thus, differential responsiveness to the il-

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\(^3\)A comparison between the last two habituation trials and the first two postcriterion trials for those infants in the lag group revealed that a significant amount of spontaneous regression had occurred, \( F(1,30) = 7.39, p < .025 \). This bias was statistically controlled by the following technique: The lag infants' scores from the first two postcriterion trials were regressed onto the scores from the last two habituation trials for both ages separately. At 5 months of age, the correlation coefficient equaled .70, the regression coefficient equaled .91, and the intercept equaled 1.41. At 7 months of age, the correlation coefficient equaled .42, the regression coefficient equaled .91, and the intercept equaled 2.30. By using the score from the last two habituation trials as the predictor variable in a regression equation, a statistically predicted lag score that included the amount of recovery due to spontaneous regression could be computed for each of the nonlag infants.
lusory versus nonillusory changes in stimuli did not appear consistently until 7 months of age. Five-month-olds showed some tendency to respond more to illusory changes, but only when the subjective-contour stimulus array was presented repeatedly as the familiar stimulus. Neither age group revealed any tendency toward response recovery to the nonillusory changes.

Response recovery to the second novel stimulus.—Two analyses of variance were carried out to examine response recovery to the second stimulus change; the first analysis compared only the looking duration for the last two familiarization trials with novel stimulus 2, whereas the second analysis added the data for novel stimulus 1. Although there was a general response recovery to the second novel stimulus for analysis 1, differential recovery among the stimulus groups was not found. (The predicted lag scores were used here also.) Similar results were obtained in the second analysis in which duration of looking at the second novel stimulus was compared with the duration of looking at the first novel stimulus. The negative results for the second novel stimulus suggest that infants were not comparing the second novel stimulus with the familiar stimulus in the same way that the first novel stimulus had been compared with the familiar one. Additionally, it appears that they did not compare the second novel stimulus with the first novel stimulus. Apparently, the presentation of the first novel stimulus introduced “carry-over effects” that disrupted the discriminations that we intended to test with the presentation of the second novel stimulus.

Response decrement to the familiar stimulus.—The use of the infant control procedure ensures that response decrement to the familiar stimulus occurred. A comparison of the decline from the first two to the last two habituation trials yielded no evidence that the decrement differed as a function of groups or age.

A number of additional measures related to response decrement—number of trials to criterion, duration of looking during the first two habituation trials, total duration of looking during response decrement—were each analyzed in separate age × group analyses of variance. Neither age nor group approached significance for any of these measures. However, the data derived from the total duration measure deviated substantially from a normal distribution. When this measure was reanalyzed using a nonparametric statistic, the Kruskal-Wallis one-way analysis of variance by ranks (Siegel 1956), the difference between groups did approach significance for the 7-month-olds, $H(2) = 4.78$, $p < .10$. The greatest difference between groups occurred between the group receiving the illusion (total looking = 58 sec) and the other two groups receiving the nonillusory (who looked 46 and 48 sec at NI1 and NI2, respectively). Thus these data provide some additional support for the inference that 7-month-olds respond differentially to illusory and nonillusory arrays.

Discussion

A key question concerns exactly what the infants perceived. The results from this study demonstrate clearly that by 7 months of age infants can discriminate a subjective-contour array from a nonsubjective-contour array. We consider these findings as evidence that infants in fact did perceive the subjective contours by this age, thereby displaying whole form perception. However, other explanations for in-
fants’ discriminations of the illusory and nonillusory stimuli must be considered.

One alternative is that the illusory and nonillusory stimulus arrays were discriminated on the basis of differences in orientation of their individual elements. This explanation, however, is unconvincing because the elements comprising the two nonillusory stimuli differed also, yet differential responding to these stimuli was much less than to pairings involving the illusion stimulus. It should also be noted that one change involving the illusory stimulus, NI₂-I, constituted twice as many orientation changes as the other, NI₁-I, yet no differential recovery between these pairs was found.

A second alternative is that differences in the symmetrical arrangement of the elements were responsible for the discrimination. That is, the illusion was discriminated from the nonillusions because all open quadrants faced in the same direction—the center of the array—in the illusion but not in the nonillusions. While this explanation appears adequate for explaining the infant’s discrimination between the illusion and nonillusion 1, it fails as an explanation for the infant’s discrimination of the illusion and nonillusion 2. In nonillusion 2, all the open quadrants also faced in the same direction, that is, away from the center of the array.

There is still an additional interpretation of the unique effect of the illusion stimulus that does not depend on the relationships among the components. It rests on the possibility that relative contour density may have differed among the arrays. Consider the illusion stimulus and NI₁. The illusion stimulus is comprised of four elements with the cutouts all in maximal proximity to one another. Since length of the black-white edge for the cutout is greater than it is for the comparable completed arc of the circle elements, there was greater contour density in I than in NI₁. However, if change in contour density were playing a major role in recovery of looking time, one would have expected as much recovery for subjects who experienced the NI₁-NI₂ shift as for those who experienced the I-NI₁ shift and twice as much change for the I-NI₂ shift because these predictions follow from the ratio of changes in the contour density for the respective stimulus arrays. These relations among looking time recovery were not observed.

There is a final alternative that cannot be as easily dismissed because no data from the present study can be brought to bear on this possibility. According to this alternative, the infants discriminated the illusion from both nonillusions because all the open quadrants faced toward the center of the array only in the illusion stimulus. Although this alternative seems highly unlikely to us, a critical test involves comparison of the response to the illusion array against response to an array containing all elements internally oriented but misaligned.

The issue of when configural perception emerges is complex. When the present findings are considered in the context of those from other studies, a fairly age-heterogeneous pattern emerges. Vurpillot et al. (1977) reported evidence of configural responding to arrangements of geometric elements in infants as young as 2 months of age. Several other studies, using a variety of schematic-face stimuli, have found configural responding only around 4 months of age. In the present study, we found evidence of configural sensitivity in 5-month-olds only in a condition that provided extensive opportunity for viewing the configured array, whereas 7-month-olds indicated sensitivity to the configured stimulus after only a brief viewing opportunity. These data suggest that the form of the often-posed question, “When can babies sense configural relations among visual elements?” is too simplistic. Apparently, humans develop an ability to organize an increasingly broad range of visual arrays over age. We may eventually be able to order dimensions along which arrays can be organized in terms of the required cognitive effort required. If so, it is likely that a family of developmental sensitivity functions could be drawn for these dimensions, revealing that “configurational sensitivity” is a process that grows over a very broad age range and that it is much less dichotomous than is usually assumed. It is hoped that future work will aim toward discovering these dimensions, quantifying them, and finding their perceptual and developmental concomitants.

References
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