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# Part–Whole Perception in Early Infancy: Evidence for Perceptual Grouping Produced by Lightness Similarity

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Four experiments using the familiarization-novelty preference procedure were conducted to determine whether 3-month-old infants can organize visual pattern information in a manner predicted by the Gestalt principle of lightness similarity. The combined results of Experiments 1 through 3 suggest that infants were able to group individual elements into larger perceptual units on the basis of lightness similarity. The combined results of Experiments 2 and 4 suggest that constituent elements actually retain an independent psychological existence within organized wholes and may be processed more efficiently than the elements of disorganized wholes. The implications of all of these results for models of part–whole perception are discussed.

Gestalt organizational principles    part–whole perception
global and local processing

The relationship between the perception of a whole pattern and the perception of its component elements has been a topic of inquiry for experimental psychology throughout this century (e.g., Kohler, 1929; Pomerantz & Pristach, 1989). For adults, the individual parts of objects, visual features such as oriented line segments, are often organized into coherent wholes. An issue of interest to contemporary perceptual developmentalists is how we come to perceive visual patterns as whole entities rather than a set of independent pieces. Some theorists have suggested that this ability is a late achievement, critically dependent on maturation of neural mechanisms and acquired knowledge derived from experiencing correlations in patterns of visual stimulation (Brunswik, 1956; Hebb, 1949; Piaget, 1954; Salapatek, 1975). Gestalt

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psychologists, on the other hand, have for some time argued that our perception of a whole entity occurs automatically in our first encounter with a visual form (Kohler, 1929). This immediate accomplishment is the direct result of a perceptual system that is constrained to obey certain organizational principles (e.g., common fate, good continuation, similarity, proximity) that specify how small units can be grouped together to form perceptual wholes.

In light of this debate, it is not surprising that contemporary work in the area of perceptual development has been directed at specifying (a) the degree of perceptual organization present in early infancy, and (b) the manner in which this organization is achieved. There is now reasonable evidence that young infants can group information from individual elements into a wholistic percept (Ghim & Eimas, 1988; Milewski, 1979; Vurpillot, Ruel, & Castrec, 1977), and the most recent work suggests that this grouping is accomplished with the use of Gestalt principles such as common fate or movement and perhaps good continuation (Bower, 1982; Slater et al., 1990; Spelke, 1982, 1988; Van Giffen & Haith, 1984).

Although there is accumulating evidence that some laws of perceptual organization are adhered to by young infants (e.g., common movement), the question of whether the law of similarity is followed has received only a small amount of empirical attention. To our knowledge, there are only two studies that have investigated the issue of whether young infants perceive visual patterns in accord with the law of similarity (Kellman & Spelke, 1983; Salapatek, 1975). Both studies concentrated largely on only one kind of similarity, namely, form or shape. Salapatek, for example, presented adults, young children, and 2-month-old infants with a visual pattern composed of a small section of one element type (e.g., squares) embedded in another element type (e.g., horizontal lines). Adults and young children fixated on the embedded element type, presumably detecting its dissimilarity to the surrounding element type in doing so. Two-month-old infants, on the other hand, did not fixate on the embedded element type. It is possible to interpret these results as indicating that the infants could not detect the dissimilarity. Alternatively, it is possible that the infants detected the dissimilar elements, even though they did not fixate on them. Furthermore, it is not known how infants might have performed with elements that were dissimilar along a different (perhaps simpler) dimension such as lightness (e.g., filled squares bounded by unfilled squares). Finally, even if the infants had fixated on the embedded elements under any such set of stimulus conditions, they may not have been able to group these elements together to form a wholistic percept of an embedded figure on a homogeneous background.

Kellman and Spelke (1983) showed that 4-month-old infants perceive the continuity of two ends of a partly occluded form (i.e., a rod) as long as the two ends of the form move together. The continuity was apparently perceived even when the two ends of the form were dissimilar in shape, texture, and color, leading Kellman and Spelke to the conclusion that infants do not use the Gestalt law of similarity as a basis for organization. One limitation of this conclusion is that the dissimilarity of the two ends of the form conflicted with their common movement. Thus, it may have been the case that infants detected the dissimilarity, but chose to weigh it less heavily than the common movement information that specified the continuity of the form. It is, therefore, not clear to what extent infants can use similarity as a grouping principle when other aspects of the visual scene are not suggesting an alternative organization.

## EXPERIMENT 1

The evidence discussed thus far leaves open the question of whether similarity can be used by young infants as an early organizational principle. Furthermore, no studies have investigated infants' perception of *lightness* similarity, the original kind of similarity that was shown to produce quite robust perceptual grouping in adults when introduced in Wertheimer's (1958) classic article. The experiments here were therefore undertaken to determine whether 3-month-old infants could achieve coherent representations for visual patterns that could be organized only by lightness similarity. In Experiment 1, the strategy was to adapt the familiarization-novelty preference procedure as a measure of perceptual grouping. One experimental group of infants (Group C) was familiarized with alternating light and dark *columns* of elements [Figure 1(a)], whereas a second experimental group of infants (Group R) was familiarized with alternating light and dark *rows* of elements [Figure 1(b)]. Both experimental groups were administered a novelty preference test in which a set of vertical stripes was presented simultaneously with a set of

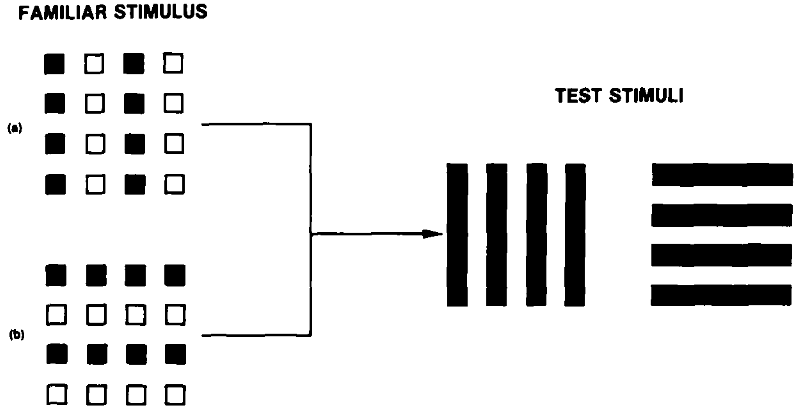

**Figure 1.** The familiarization and test stimuli used in Experiment 1.

horizontal stripes (also shown in Figure 1). A control group was administered a spontaneous preference test (i.e., no familiarization) with the vertical and horizontal stripes. If the Group C infants are perceiving the familiar stimulus shown in Figure 1(a) as a set of columns, then the preferred test stimulus should be the horizontal stripes. Similarly, if the Group R infants are perceiving the familiar stimulus shown in Figure 1(b) as a set of rows, then the preferred test stimulus should be the vertical stripes. The control group was not expected to show a preference for either test stimulus (Shepherd, Fagan, & Kleiner, 1985).

## Method

***Subjects.*** The subjects were 72 3-month-old infants. Forty-six of the infants were males, and 26 were females. An additional 17 infants were tested, but their data were not included in the analyses because of fussing or crying (12 infants), a position preference of greater than 95% (4 infants), and experimenter error (1 infant).

***Apparatus.*** Infants were tested with the portable visual preference apparatus adapted from that used by Fagan (1970). The apparatus consists of an enclosed viewing chamber with a hinged display stage that is 85 cm long and 29 cm high. The stage is evenly illuminated by a 60 Hz fluorescent lamp and contains two compartments into which 17.7 × 17.7 cm stimulus cards can be fitted by an experimenter. The center-to-center distance between the two compartments is 30 cm. Midway between the stimulus compartments is a .625 cm (diameter) peephole through which an observer can view the infant's visual fixations to the stimuli. When the stage is open, the infant can see only the experimenter's face. When the stage is closed, it is positioned approximately 30 cm above the infant, and the infant can see only the two stimulus cards and the gray surround of the viewing chamber.

***Stimuli.*** The familiar stimuli were alternating filled and unfilled *columns* or *rows* of black Chartpak M489-490 symbols (squares or diamonds) on white cards. Each stimulus consisted of 16 symbols. The symbols were 1.27 cm on a side and subtended 2.42° of visual angle. The center-to-center distance between the symbols in both horizontal and vertical planes was 2.54 cm (4.84°). The patterns containing the square elements are the familiar stimuli shown in Figure 1.

The test stimuli consisted of four black Chartpak stripes, each being 8.89 cm in length (16.50°) and 1.27 cm in width (2.42°), oriented either horizontally or vertically on white cards. The center-to-center distance between the lines was 2.54 cm (4.84°). These stimuli are essentially square-wave grating targets with a spatial frequency of 0.21 cycles/degree. They are shown in Figure 1.

***Procedure.*** Each infant was placed in a reclining position on a seated parent's lap underneath the preference apparatus. On each trial, an experimenter would load the stimuli into the compartments on the display stage, elicit the attention of the infant, center his or her gaze, and then fold up the stage exposing the stimuli to the infant. The experimenter recorded the infant's fixations by observation through the peephole. The criterion for fixation was observing corneal reflection of the stimulus over the infant's pupil. This corneal reflection recording procedure is quite reliable; the mean interobserver reliability estimate obtained using this procedure in our laboratory is .92. Two experimenters recorded each infant's fixations in order to prevent experimenter bias. The first was recorded during the familiarization phase and the second, unaware of the familiarization condition, was recorded during the preference test phase.

The infants were randomly divided into two experimental groups and one control group with 24 infants in each. Infants in Group C were familiarized with alternating filled and unfilled columns of elements, whereas infants in Group R were familiarized with alternating filled and unfilled rows of elements. The familiar elements for half of the infants in each group were squares; for the other half, they were diamonds. For half of the infants in Group C, the far left column was composed of filled elements; for the other half, it was composed of unfilled elements. Similarly, for half of the infants in Group R, the top row was composed of filled elements; for the other half, it was composed of unfilled elements. For both experimental groups, the stimuli were shown to the infants for six 15-s periods. Infants in the control group were *not* presented with a familiarization stimulus; they received only a preference test.

All three groups of infants were administered the same preference test. Each infant was presented with horizontal stripes paired with vertical stripes for two 10-s periods. For all three groups, the left–right positioning of the horizontal and vertical stripes was counterbalanced in the first test period and reversed in the second test period.

## Results and Discussion

***Familiarization Phase.*** The results from the familiarization phase are shown in Table 1 (p. 24), where looking time has been collapsed across the first and second halves of familiarization for the two experimental groups. Decrements in looking time from the first to the second half of familiarization can be observed in both groups.

A three-way analysis of variance (ANOVA), experimental group (C vs. R) × element type (square vs. diamond) × familiarization trials (1–3 vs. 4–6), was performed on the individual scores averaged over blocks of three familiarization trials. The effect of familiarization trials was found to be significant, $F(1, 44) = 52.44$, $p < .001$, suggesting that both experimental groups habitu-

TABLE 1
Mean Fixation Times (Seconds) and Standard Deviations During the Familiarization Trials of Experiment 1

| | Trials | |
|---|---|---|
| | 1,2,3 | 4,5,6 |
| Organization of Familiar Stimulus | M (SD) | M (SD) |
| Column | 8.89 (2.80) | 5.90 (2.87) |
| Row | 9.24 (2.44) | 6.62 (3.67) |

ated to the stimuli presented during familiarization. No other effects were reliable, $p > .05$ in each instance.

***Preference Test Phase.*** To determine whether infants were achieving an organized percept for the familiar arrays of elements, a percentage preference score for vertical was calculated for each infant. These scores were obtained by dividing the time spent looking at the vertical stripes by the total looking time to both patterns and then converting to percentages by multiplying by 100.

The percentage preference for the vertical stripes for the experimental and control groups can be seen in Table 2. It was expected that infants in the control group would display a percentage preference for the vertical stripes of approximately 50% (Shepherd et al., 1985). If infants were capable of organizing the arrays of elements on the basis of lightness similarity, then the preference for the vertical stripes should be below 50% for Group C and above 50% for Group R. As can be seen in Table 2, the expected pattern of results was observed. The preference for the vertical stripes was close to 50% for the control group but was well above and below 50% for Groups R and C, respectively. Planned comparisons (one-tailed) revealed that the difference between the Group R and C means was significant, $t(46) = 3.65, p < .001$. In addition, planned comparisons of the Group R and C means to the control mean revealed that the Group R and control means were reliably different, $t(46) = 2.15, p < .025$, and the Group C and control means were marginally so, $t(46) = 1.55, p < .10$. Single-factor, between-subjects ANOVAs revealed

TABLE 2
Mean Vertical Stripe Preference Scores (%) for Experiment 1

| | R | C | Control |
|---|---|---|---|
| | M (SD) | M (SD) | M (SD) |
| Vertical Preference Score | 60.99 (16.18) | 43.04 (17.78) | 50.76 (16.76) |

*Note.* $n = 24$ for each group.

that the magnitude of the vertical preference was not affected by the familiar element type (square vs. diamond) in either experimental group ($p > .10$ in each instance).

There are at least two different theoretical interpretations for the preferences observed in the two experimental groups. A Gestalt interpretation is that the infants perceived the individual elements of the arrays and grouped these elements into larger perceptual units (either rows or columns) on the basis of lightness similarity. A second interpretation is suggested by linear systems analysis (Banks & Ginsburg, 1985; Banks & Salapatek, 1981; Ginsburg, 1986). Linear systems analysis assumes that the visual system performs a Fourier analysis on visual stimuli and that the information from this analysis provides the basis for pattern perception. Furthermore, linear systems analysis allows one to predict the detectability of a visual stimulus if one knows the spatial frequency make-up (Fourier transform) of the stimulus and the sensitivity of the visual system to different spatial frequencies (the contrast sensitivity function).

Ginsburg (1986) applied a linear systems analysis to the problem of Gestalt grouping in adults. Ginsburg's approach was to obtain Fourier transforms for a number of multielement stimuli that produce perceptual grouping and pass them through a computer which acts as a low-pass spatial frequency filter (approximating the contrast sensitivity function of the human visual system). For each stimulus, this computation yields a "reconstructed image" which is isometric with the information represented in the cortex if the visual system is performing such an analysis. Ginsburg was able to demonstrate that the reconstructed images can predict the perceptual grouping phenomena produced by the original stimuli. Because the low-pass filter does not transmit high spatial frequencies, the elements of these stimuli were no longer resolvable and "merged" together to form larger perceptual units (e.g., rows or columns).

Ginsburg's (1986) analysis with adults suggests the possibility that the preferences of Experiment 1 could be the result of low-pass spatial frequency filtering by the 3-month-old visual system. Loss of high spatial frequency information might have resulted in one of two possible representations of the familiar stimuli, depending on the severity of the loss. In the case of the more severe loss, the infant's visual system may have filtered out the filled *and* unfilled element information *within* the columns or rows. This kind of loss would have given rise to a vertical "grating-like" percept for Group C and a horizontal "grating-like" percept for Group R The preference test performance might, therefore, reflect generalization from a representation of the familiar stimulus as "two dark vertical (or horizontal) bars on a light background" to "four dark vertical (or horizontal) bars on a light background."

A less severe loss of spatial frequency might result in the infant's visual system filtering out just the unfilled element information. In other words, only the filled elements would be detectable. If the infants were able to organize the filled elements into larger perceptual units on the basis of the Gestalt principle of proximity, then infants in Group C would have perceived two columns of dark elements, and infants in Group R would have perceived two rows of dark elements. Infants in Group C would then have generalized from the columns to vertical stripes, and infants in Group R would have transferred their habituation from the rows to horizontal stripes. An account of this nature, therefore, implies adherence to a grouping principle, but not the one hypothesized.

To investigate the possibility that the preference results of Experiment 1 could be interpreted in terms of spatial frequency filtering, one of the familiar stimuli (i.e., the columns of square elements) was subjected to a Fourier analysis that removed spatial frequencies above 4 cycles/degree, the cutoff spatial frequency for 3-month-old infants as estimated by preferential looking techniques (e.g., Atkinson, Braddick, & Moar, 1977; Banks & Salapatek, 1978). This Fourier analysis was also performed for patterns in which the shape of the filled or unfilled elements was changed from square to diamond. If the results of Experiment 1 can be explained at least in part by spatial frequency filtering, then either the change in the unfilled elements or the changes in both the filled and unfilled elements would not be detectable. The

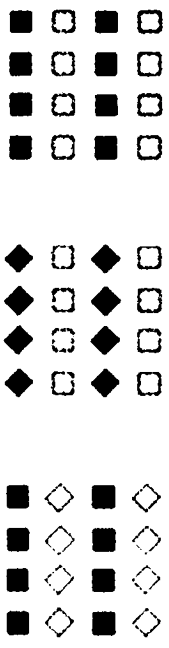

**Figure 2.** Reconstructed patterns resulting from the Fourier analysis where sine wave components above 4 cycles/degree have been removed.

global column-like organization of the patterns would still emerge, but not the shape of the individual elements within the columns. Figure 2 shows the reconstruction of the patterns. As can be seen, the contours of the filled and unfilled elements have lost some sharpness, but both have retained enough of their shape to be distinguishable.

The results of the Fourier analysis suggest that infants had access to the element information contained within the rows and columns of the patterns of Experiment 1 and favors a Gestalt interpretation of the results. In addition, the Fourier analysis predicts that changes in the filled and unfilled elements should be distinguished by 3-month-old infants. Experiment 2 sought to provide behavioral confirmation of this prediction.

## EXPERIMENT 2

Two discrimination tasks were used to decide further among the alternative explanations of the results of Experiment 1. Familiarization with columns or rows of elements was followed by a preference test in which the choice was between the familiar array and an array differing only in the shape of the filled or unfilled elements. A preference for the novel array would suggest that infants are detecting and processing the element information contained within the columns or rows.

Representative experimental sequences depicting a change in the *filled* elements are shown in Figure 3. Figure 3(a) displays a sequence in which infants are familiarized with filled and unfilled columns of square elements and are then tested with the familiar array and a novel array consisting of unfilled squares and filled diamonds. Figure 3(b) illustrates a corresponding experimental sequence for patterns consisting of rows of elements. Discrimi-

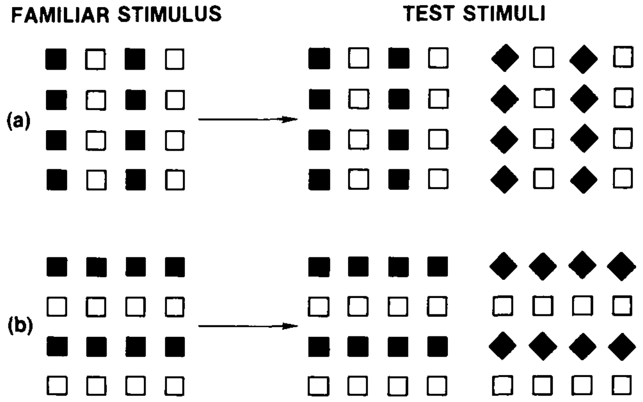

**Figure 3.** The familiarization and test stimuli used to assess infants' sensitivity to a change in the filled elements.

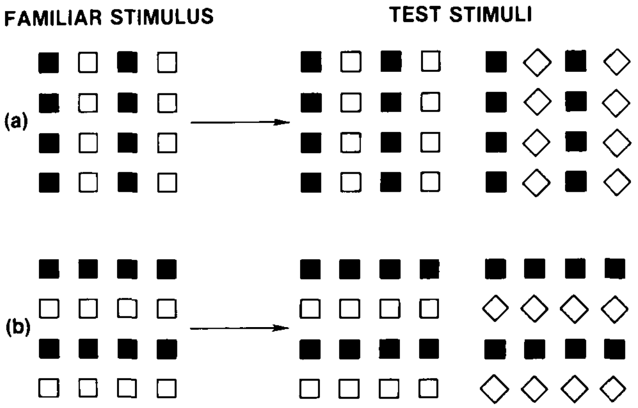

Figure 4. The familiarization and test stimuli used to assess infants' sensitivity to a change in the unfilled elements.

nation tasks requiring infants to detect a change in the *unfilled* elements are depicted in Figure 4. In Figure 4(a), the familiar stimulus consists of alternating light and dark columns of square elements, and the novel pattern differs in that the unfilled elements are diamonds. Figure 4(b) illustrates a corresponding sequence for patterns consisting of rows of elements. If, when presented with familiar stimuli of Experiment 1, infants detected and processed element information, then we would expect them to show preferences for the patterns containing the novel element type, whether they are filled or unfilled. If, however, the infants in Experiment 1 could not process either the filled or unfilled element information, then it is predicted that they would *not* prefer the arrays containing the novel element type (filled or unfilled). An intermediate possibility is that the infants in Experiment 1 may have processed filled element information but not unfilled element information. In this case, we would expect the infants to exhibit above-chance discrimination performance with a change in the filled elements, but not with a change in the unfilled elements.

## Method

***Subjects.*** The subjects were 32 3-month-old infants. There were 17 males and 15 females. Four additional infants were tested, but not included in the data analysis because of fussiness or crying ($n = 3$) or position preference ($n = 1$).

***Apparatus and Stimuli.*** The apparatus was identical to that used in Experiment 1. Eight different stimuli were used in Experiment 2. Four of the stimuli were carried over from Experiment 1. These were alternating filled and unfilled (a) columns of square elements, (b) columns of diamond elements, (c) rows of square elements, and (d) rows of diamond elements. Four additional stimuli were created for Experiment 2. All were hybrid patterns in that they contained both square and diamond elements. They included alternating (e) columns of filled squares and unfilled diamonds, (f) columns of unfilled squares and filled diamonds, (g) rows of filled squares and unfilled diamonds, and (h) rows of unfilled squares and filled diamonds. The element size and interelement spacing values used in Experiment 1 were retained in Experiment 2.

***Procedure.*** Each of the 32 infants was randomly assigned to one of two types of discrimination tasks. In one task, the filled elements changed ($n = 16$); in the other, the unfilled elements changed ($n = 16$). In both tasks, the change in the elements was from square to diamond or vice versa. Within each discrimination task, half of the infants ($n = 8$) were presented with columns and half were presented with rows. Within each of these groups, half of the infants ($n = 4$) were familiarized with patterns containing a single element type, either all square ($n = 2$) or all diamonds ($n = 2$); the other half were familiarized with hybrid patterns, either filled squares plus unfilled diamonds ($n = 2$) or unfilled squares plus filled diamonds ($n = 2$).

Each discrimination task consisted of six 15-s familiarization trials in which the infant was repeatedly presented with two identical copies of the same stimulus. Immediately after the familiarization period, two 10-s test trials were administered in which the familiar stimulus was presented with the appropriate novel stimulus. The left–right positioning of the novel and familiar stimuli were appropriately counterbalanced across infants on the first test trial and then reversed on the second test trial. All other procedural details were unchanged from the first experiment.

## Results and Discussion

***Familiarization Phase.*** Table 3 (p. 30) presents the mean looking times and standard deviations averaged over blocks of three trials. An ANOVA, combination of elements in the familiar stimulus (redundant vs. discrepant) × organization of the familiar stimulus (column vs. row) × trials (1–3 vs. 4–6), was performed on the individual looking times. Only the effect of trials was significant, $F(1, 28) = 35.77$, $p < .001$; no other main effects were significant, $F(1, 28) < 1$, $p > .10$ in each instance.

That the infants did not display longer looking times for the discrepant element patterns (squares and diamonds) as compared with the redundant element patterns (squares or diamonds) is perhaps surprising in light of a recent report that 6-month-old infants prefer different-element stimuli over same-element stimuli (Colombo, O'Brien, Mitchell, & Horowitz, 1986). In one representative condition from the Colombo et al. study, infants preferred

TABLE 3
Mean Fixation Times (Seconds) and Standard Deviations During the Familiarization Trials of Experiment 2

| | | Trials | |
|---|---|---|---|
| | | 1,2,3 | 4,5,6 |
| Combination of Elements | Organization | *M* (*SD*) | *M* (*SD*) |
| Redundant (Square or Diamond) | Column | 11.27 (2.37) | 8.94 (2.91) |
| | Row | 10.80 (2.72) | 8.34 (3.83) |
| Discrepant (Square and Diamond) | Column | 9.93 (2.85) | 8.25 (2.76) |
| | Row | 9.97 (2.28) | 7.77 (3.39) |

a pattern consisting of a plus sign and a diamond over a pattern consisting of two trapezoids. The Colombo et al. study differed from the present one on a number of dimensions (e.g., ages of infants tested, number of elements in the stimulus patterns, shapes of individual elements), any one or combination of which could have given rise to the differences in results.

An attempt was made to test one explanation of the differences in results between this experiment and that of Colombo et al. (1986). Colombo et al. found that infants preferred different-element stimuli over same-element stimuli in a paired-comparison procedure, a within-subjects comparison. In this experiment, attractiveness of the various stimuli was determined by comparing the familiarization looking times obtained from different groups of subjects, a between-subjects comparison. We therefore sought to determine whether infants would display preferences for our discrepant-element stimuli in the kind of paired-comparison procedure used by Colombo et al. Each of 16 infants was presented with one of the four possible test-phase pairings used in Experiment 2 for two 10-s looking periods. The left–right positioning of the redundant versus discrepant-element stimuli on the first test trial was counterbalanced across all infants and reversed on the second trial. Across all the patterns tested, the infants showed a mean preference for the discrepant-element stimuli of only 52.66% ($SD$ = 13.37), which was not significantly different from chance, $t(15) = 0.80, p > .10$, one-tailed. There was thus no evidence for a preference for the discrepant-element stimuli, even when measured with the paired-comparison procedure.

Two additional, more specific analyses were conducted to determine if infants' looking times were affected by the particular combination of elements with which they were familiarized. For the *redundant-element* stimulus patterns, the question was whether infants found square elements to be more attractive than diamond elements or vice versa. An ANOVA, elements (square vs. diamond) × organization (column vs. row) × trials (1–3 vs. 4–6), revealed only a significant effect of trials, $F(1, 12) = 31.90, p < .01$. There were no other reliable effects, $ps > .05$. Of interest with the *discrepant-element* stimulus patterns was whether infants found the combination of filled squares and unfilled diamonds to be more attractive than unfilled squares and filled diamonds. An ANOVA, elements × organization × trials, once more revealed only a significant effect of trials, $F(1, 12) = 9.55, p < .01$. No other effects were reliable, $F < 1.1, p > .10$ in each case.

***Preference Test Phase.*** A novelty preference score in percentage was computed for each infant by dividing the looking time to the novel stimulus by the total looking time to both stimuli and then multiplying by 100. The mean preference scores, together with the corresponding standard deviations and $t$ values (vs. chance), are shown in Table 4. As can be seen, infants showed novelty preferences significantly above the chance value of 50% in both discrimination conditions. After being familiarized with an array of elements, infants displayed a reliable preference for a novel array that differed only in the identity of the filled or unfilled elements.

A two-factor ANOVA was performed to determine if the individual novelty preferences were affected by the organization of elements (column vs. row), discrimination condition (filled change vs. unfilled change) or the interaction of these factors. No reliable effects were found, $F(1, 28) < 1, p > .20$.

The results of Experiment 1 can now be more definitely interpreted in light of the above-chance discrimination performance for *both* the filled and unfilled element changes. In particular, the results of Experiment 2 suggest that any spatial frequency filtering which may have occurred during the familiarization phase of Experiment 1 was not sufficient to block the processing of filled and unfilled element information. The most parsimonious explanation of the results of Experiment 1 appears to be that infants detected the individual elements of the arrays and grouped these elements into larger perceptual units (i.e., rows or columns) on the basis of lightness similarity. The combined results of Experiments 1 and 2 are, moreover, consistent with other

TABLE 4

Mean Novelty Preferences in Percentages, Standard Deviations, and $t$ Values (vs. Chance) as a Function of Stimulus Change

| | Stimulus Change | |
|---|---|---|
| | Filled Elements | Unfilled Elements |
| *M* (*SD*) | 59.36 (15.84) | 55.16 (11.12) |
| *t* vs. chance | 2.36* | 1.86** |

*$p < .01$, one-tailed. **$p < .05$, one-tailed.

reports that infants have knowledge of both local and global information when processing visual patterns (e.g., Ghim & Eimas, 1988; Quinn & Eimas, 1986).

## EXPERIMENT 3

The results of Experiments 1 and 2 suggest that young infants can achieve coherent percepts resulting from grouping operations that link individual elements by lightness similarity. Experiment 3 seeks to provide converging evidence for this conclusion by investigating infant performance in two discrimination tasks, one involving the familiar stimuli of Experiment 1 and the other involving random arrangements of the filled and unfilled elements. If different global representations were formed for the familiar stimuli of Experiment 1 (e.g., rows vs. columns of squares), then it should be possible to demonstrate discrimination between them, even though one is merely a 90° rotation of the other. The rotation results in a new global identity for the arrangement of elements, even though the local element information does not change. If no such global representation is formed and infants are processing information about local elements, then discrimination should be more difficult, given that the elements in both patterns remain constant as filled and unfilled squares. The only means by which discrimination could occur under these circumstances is if infants represent the location of particular elements and thereby detect that one or more of the squares in particular positions have changed from filled to unfilled. Of course, such a strategy would not be expected to yield consistent discrimination performance given that some of the squares do not change in lightness. By similar reasoning, poor performance would be expected in a discrimination between a pattern without global organization and its corresponding 90° rotation. Under these conditions, it may not be possible to form global units of processing, leaving the infant with a representation dominated by local element information which again remains constant in both patterns.

Figure 5 depicts the experimental procedure that allows us to test the infant's ability to distinguish between the organized and unorganized pairs of patterns. In the organized pattern-discrimination condition shown in Figure 5(a), infants are familiarized with one organized pattern and then given a preference test that pairs this pattern and its 90° rotation. In the unorganized pattern-discrimination condition shown in Figure 5(b), infants are familiarized with a random arrangement of elements and are likewise tested with this pattern and its 90° rotation.

### Method

***Subjects.*** The subjects were 32 3-month-old infants. There were 16 males and 16 females. Seven additional infants were tested, but not included in the data analysis because of fussiness or crying ($n = 3$) or position preference ($n = 4$).

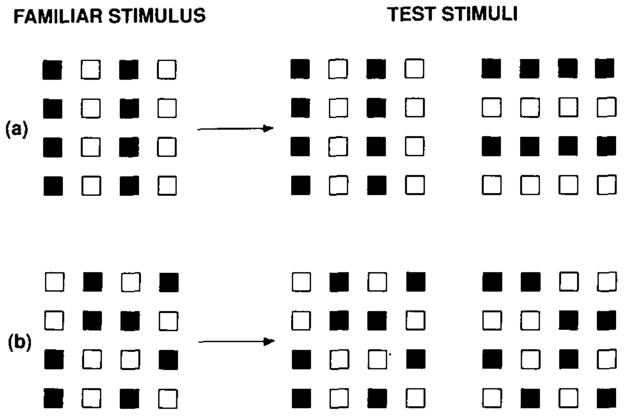

**Figure 5.** The familiarization and test stimuli used in Experiment 3.

***Apparatus and Stimuli.*** The apparatus was the same one used in the first two experiments. The stimuli used in the organized pattern-discrimination task were used in Experiments 1 and 2. They were alternating filled and unfilled columns or rows of squares. They are shown in Figure 5(a). Two stimuli were used in the unorganized pattern-discrimination task. One was a random arrangement of the filled and unfilled elements within the positions of the 4 × 4 array. The other stimulus was a 90° clockwise rotation of the first. These stimuli are presented in Figure 5(b).

***Procedure.*** Half of the infants were randomly assigned to each of the two discrimination tasks. As in Experiment 2, each discrimination task consisted of six 15-s familiarization trials in which the infant is repeatedly presented with two identical copies of the same stimulus. For those infants assigned to the organized pattern-discrimination task, half were familiarized with rows, the other half with columns. For those infants in the unorganized pattern-discrimination task, half were familiarized with the random arrangement of elements, the other half with its 90° rotation.

Infants in both groups were given two 10-s preference test trials that paired the familiar stimulus with its novel 90° rotation. Within each group, the left–right positioning of the familiar and novel stimuli was counterbalanced on the first test trial and reversed on the second test trial.

## Results and Discussion

***Familiarization Phase.*** Table 5 (p. 34) shows the mean looking times and corresponding standard deviations for blocks of three trials. An ANOVA, trials (1–3 vs. 4–6) × discrimination condition (organized vs. unorganized), was performed on the individual looking times. There was a significant effect of trials, $F(1, 30) = 19.95, p < .001$, indicating a reliable decrease in looking

TABLE 5
Mean Fixation Times (Seconds) and Standard Deviations During the Familiarization Trials of Experiment 3

| | Trials | |
|---|---|---|
| | 1,2,3 | 4,5,6 |
| Familiar Stimulus | *M* (*SD*) | *M* (*SD*) |
| Organized (Row or Column) | 10.97 (2.25) | 8.77 (3.23) |
| Unorganized (Random Arrangement or 90° Rotation) | 10.54 (3.07) | 9.07 (2.96) |

times across trials, and further suggesting that both groups were habituating to the patterns. There were no other effects that reached significance at the .05 level, $F < 1$ in each case.

Two further analyses were conducted to determine if infant looking times were affected by the identity of the familiar stimulus within each discrimination condition. For the organized discrimination condition, a trials × familiar stimulus (row vs. column) analysis yielded only a significant effect of trials, $F(1, 14) = 17.33$, $p < .004$; for the unorganized discrimination condition, a trials × familiar stimulus (random arrangement vs. 90° rotation) analysis again revealed only a reliable trials effect, $F(1, 14) = 9.33$, $p < .008$. Infant looking times were thus unaffected by whether the familiar stimulus was a set of rows versus columns or a random arrangement versus its 90° rotation.

***Preference Test Phase.*** The mean novelty preference scores are shown in Table 6, together with their standard deviations and *t* values (vs. chance). These scores were computed as in Experiment 2. Only the mean for the organized pattern-discrimination task was reliably above the 50% chance level. In addition, a *t* test comparing the two means uncovered a marginally reliable difference, $t(30) = 1.56$, $p < .10$, one-tailed.

Two single-factor ANOVAs were performed on the individual preference scores obtained in the two discrimination tasks to determine if there was an

TABLE 6
Mean Novelty Preferences in Percentages, Standard Deviations, and *t* Values (vs. Chance) for the Two Pattern-Discrimination Tasks of Experiment 3

| | Pattern-Discrimination Task | |
|---|---|---|
| | Organized | Unorganized |
| *M* (*SD*) | 58.06 (13.61) | 49.08 (18.56) |
| *t* vs. chance | 2.37* | −0.19 |

*$p < .025$, one-tailed.

effect of familiar stimulus (row vs. column in the organized task; random arrangement vs. 90° rotation in the unorganized task); neither effect was significant, $F < 1$ in each case.

The above-chance performance observed for infants in the organized pattern-discrimination task provides further evidence suggesting that infants are capable of forming global representations of organized patterns. When considered together with the findings of Experiment 2, this result also supports the conclusion that infants are capable of processing both the local and global aspects of organized patterns.

The chance discrimination performance observed among infants in the unorganized pattern-discrimination task suggests that these infants may not have been able to develop a representation containing global information. With this type of pattern, the random arrangement of elements may not permit perceptual grouping of the elements into larger perceptual units, leaving the infant with a representation containing only local element information. Given that the elements of both patterns involved in the discrimination task are square and also that only some of these elements change from light to dark (or vice versa), representations containing only local information would not be expected to allow for consistent above-chance discrimination performance.

## EXPERIMENT 4

The combined results of Experiments 1 through 3 suggest that infants can use lightness similarity to organize at least some patterns of visual information. In this respect, this article has emphasized only one direction in the whole–part relationship. That is, the Gestalt similarity grouping principle describes how particular configurations of elements can affect the perception of a whole. But how does the perception of a whole affect the perception of its component parts? Another way of asking this question is: How does the formation of a global unit of processing affect processing of the local elements? There are at least three current descriptions of the effects of global, wholistic perception on the perception of local parts. What seems to be implied by the original Gestalt position is that perception of *whole patterns* makes perception of the individual elements within them less likely. Specifically, the component parts are harder to perceive individually when grouped to form larger perceptual units. Following in this tradition, Pomerantz and Pristach (1989) recently coined the term *perceptual glue* to describe whatever hypothetical agent may be binding together the elements of visual patterns. A second position on part–whole relations is that, when individual elements are grouped together, they form higher order emergent features (e.g., in this experiment, rows or columns; Pomerantz, Sager, & Stoever, 1977). The formation of these emergent features does not, however, make the perception of individual elements within them less likely. Both the elements and emergent features can be independently accessed during processing (Enns & Prinzmetal, 1984; Palmer, 1977; Pomerantz & Pristach, 1989). A third possible description of part–whole relations is found in the global-to-local model of visual pattern processing (Navon, 1977). This model maintains that the output resulting from the grouping of local elements is an organized whole or global unit of processing. This global unit enjoys a speed of processing advantage over the local elements and can also serve to direct, and thereby, facilitate subsequent processing of the local elements. A global-to-local model therefore makes a prediction in opposition to the Gestalt view: part processing should actually be enhanced in the context of an organized whole.

In Experiment 2, evidence was obtained indicating that infants perceived changes in the local elements of patterns they had also responded to as organized wholes in Experiments 1 and 3. In Experiment 4, we sought to determine how the processing of elements would be affected by removing the overall organization of a visual pattern. In particular, we investigated infants' discrimination of filled and unfilled element changes in patterns without global organization. Experiment 4 was therefore identical to Experiment 2 in its design characteristics, with the exception that the patterns used were *random* arrangements of filled and unfilled elements. Figure 6 displays the representative experimental sequences. As can be seen in Figure 6(a), infants were familiarized with a random array of filled and unfilled squares and were then given a preference test between the familiar pattern and a pattern in which the *filled* elements had been changed to diamonds. Figure 6(b) depicts a corresponding sequence in which the *unfilled* elements change from squares to diamonds. If parts are more easily perceived when they are "unglued" from the whole, then we would expect highly reliable preferences for the

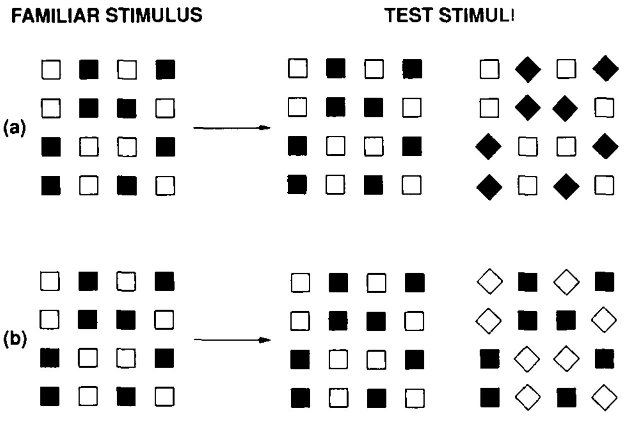

**Figure 6.** The familiarization and test stimuli used in Experiment 4.

novel pattern, above those observed in Experiment 2. If the processing of parts is unaffected by their being constituents of larger perceptual units as is implied in the most current description of the emergent feature view (Pomerantz & Pristach, 1989), then we would expect novelty preferences comparable to those found in Experiment 2. Finally, if the processing of parts is actually enhanced when they are embedded in organized wholes, as is true in a global-to-local account of pattern perception, then we would expect poor discrimination performance relative to that observed in Experiment 2.

### Method

***Subjects.*** Thirty-two 3-month-old infants served as subjects. Twenty of the infants were males and 12 were females; 4 additional infants were excluded because of fussing or crying.

***Apparatus and Stimuli.*** The apparatus described in earlier experiments was again used with four stimuli. The four stimuli were identical to those used in Experiment 2, with the exception that the positions of the filled and unfilled elements within the 4 × 4 array were randomized. The four stimulus patterns could be differentiated on the basis of the elements contained in them: Pattern 1, all squares; Pattern 2, all diamonds; Pattern 3, filled squares and unfilled diamonds; and Pattern 4, unfilled squares and filled diamonds.

***Procedure and Design.*** As in Experiment 2, each of the 32 infants was randomly assigned to a discrimination task in which either the filled elements changed ($n = 16$) or the unfilled elements changed ($n = 16$). Within each of these groups, half of the infants were familiarized with patterns containing a single element type, either all square ($n = 4$) or all diamond ($n = 4$); the other half were familiarized with hybrid patterns, either filled squares plus unfilled diamonds ($n = 4$) or unfilled squares plus filled diamonds ($n = 4$).

The preference test was conducted in the same manner as in Experiment 2: The choice was between the familiar array and an array differing only in the identity of the filled or unfilled elements. All other procedural details of the preference test were identical to those of Experiment 2.

### Results and Discussion

***Familiarization Phase.*** Table 7 (p. 38) shows the mean looking times and corresponding standard deviations averaged over blocks of three trials. An ANOVA, trials (1–3 vs. 4–6) × combination of elements in the familiar stimulus (redundant vs. discrepant), was performed on these data. There was a significant effect of trials, $F(1, 30) = 8.64$, $p < .01$, indicating a reliable decrement in looking times and suggesting that the infants habituated to the patterns with repeated exposure. No other effects were significant ($F < 1$ in

TABLE 7
Mean Fixation Times (Seconds) and Standard Deviations During the Familiarization Trials of Experiment 4

| | Trials | |
|---|---|---|
| | 1,2,3 | 4,5,6 |
| Combination of Elements | *M* (*SD*) | *M* (*SD*) |
| Redundant (Square or Diamond) | 10.48 (3.60) | 9.18 (3.70) |
| Discrepant (Square and Diamond) | 9.93 (3.91) | 8.94 (4.17) |

each case). Additional analyses were conducted to determine if infants were attracted to particular combinations of elements. For those infants familiarized with redundant-element stimuli, a trials × elements (square vs. diamond) ANOVA revealed only a marginally reliable effect of trials, $F(1, 14) = 3.99$, $p < .10$; for those infants familiarized with discrepant-element stimuli, a trials × elements (filled squares plus unfilled diamonds vs. unfilled squares plus filled diamonds) also uncovered a marginally significant effect of trials, $F(1, 14) = 2.90$, $p < .10$. In each of these analyses, no other effects were found to be reliable, $F(1, 14) < 1$, $p > .10$ in all cases.

***Preference Test Phase.*** A novelty preference score was computed for each infant. The mean preference scores, together with their standard deviations and *t* values (vs. chance) are shown in Table 8. As can be seen, infants showed only a marginally reliable preference for patterns containing novel *filled* elements; infants showed no evidence of preferential responding to patterns containing novel *unfilled* elements. These comparisons against chance suggest that infants have difficulty processing local element changes in patterns without global organization. The reader may recall that comparisons against chance performed on the mean novelty preferences obtained in Experiment 2 revealed that infants were capable of processing changes in the *filled* and *unfilled* elements of organized patterns. A direct comparison of the mean

TABLE 8
Mean Novelty Preferences in Percentages, Standard Deviations, and *t* Values (vs. Chance) as a Function of Stimulus Change for Experiment 4

| | Stimulus Change | |
|---|---|---|
| | Filled Elements | Unfilled Elements |
| *M* (*SD*) | 58.65 (20.20) | 46.93 (20.16) |
| *t* vs. chance | 1.71* | −0.62 |

*$p < .10$, one-tailed.

preference results of Experiments 2 and 4 revealed that, whereas there was no significant difference in the *filled* element discrimination task, $t(30) = .11$, $p > .10$, one-tailed, there was a marginally reliable difference on the *unfilled* element discrimination task, $t(30) = 1.43$, $p < .10$, one-tailed. The combined results of Experiments 2 and 4 are therefore not consistent with a strict Gestalt account of part–whole relations and actually hint at the possibility that the processing of low-level elements is more efficient when those elements are embedded in organized wholes relative to unorganized wholes.

## GENERAL DISCUSSION

Previous work in the area of infant pattern perception has established that young infants can group information from individual elements into a wholistic perception of the pattern (Milewski, 1979; Vurpillot et al., 1977). More recent work has provided a beginning towards identifying Gestalt organizational principles that infants may use as they group individual elements into coherent percepts (e.g., Kellman & Spelke, 1983; Van Giffen & Haith, 1984). We believe this to be a promising approach and in these experiments attempted not merely to demonstrate the presence of perceptual organization in early infancy, but also to specify, as precisely as possible, the basis for this organization.

In Experiment 1, we constructed visual patterns consisting of elements that could be grouped into larger units (e.g., columns or rows) only on the basis of lightness similarity. A preference test, pairing horizontal and vertical stripes, revealed infant generalization of habituation from columns of elements to vertical stripes and from rows to horizontal. This result was taken as evidence for perceptual grouping produced by lightness similarity. To our knowledge, this experiment represents the first demonstration that young infants can use the Gestalt principle of similarity to organize visual pattern information.

The results of Experiment 2 revealed that the grouping effects observed in Experiment 1 were not a by-product of spatial frequency filtering by the young infant's visual system. After familiarization with an organized array of elements, infants displayed preferences for novel arrays differing only in the shape of either the unfilled or filled elements. This finding indicates that the infant's resolution acuity (e.g., Dobson & Teller, 1978) and contrast sensitivity (e.g., Banks & Salapatek, 1978) was mature enough to allow for the processing of information about individual elements. Such a result suggests that the generalization behavior observed in the preference tests of Experiment 1 was due to a *grouping* process: *individual elements* being linked together to form larger perceptual units. Further evidence consistent with this conclusion was obtained in Experiment 3. Infants in this experiment discriminated between patterns that could be organized into rows and columns on the basis of lightness similarity. However, the infants did not discriminate between two patterns that were also 90° rotations of each other, but which could not be organized by lightness similarity.

Experiment 4 assessed the ability of infants to process information about the elements of a visual pattern without global organization. The results revealed that infants had difficulty perceiving changes in both the filled and unfilled elements of the unorganized arrays. The combined findings of Experiments 2 and 4 have parallels in the adult literature on visual form perception. Weisstein and Harris (1974), for example, found that adults' detection of a line segment was better when it was embedded in a coherent, three-dimensional array rather than in a variety of less coherent, flattened arrays. Furthermore, Homa, Haver, and Schwartz (1976) found that identification of facial features (e.g., nose, mouth, eyes) was superior when the features were presented in the context of an organized, schematic face relative to a scrambled face in which the features did not appear in their normal position. In infancy as well as in adulthood, then, there is evidence that knowledge about a stimulus element is increased by having it become part of a larger perceptual unit.

## An Account of Part–Whole Relations

It is interesting to consider the beginnings of a model that can account for the processing of parts in organized and unorganized wholes. With an organized whole, we assume that, in the very act of *grouping*, some automatic processing of element information occurs. After all, how else could a perceptual system determine *which elements go together*? Once this grouping algorithm has produced emergent features (e.g., rows or columns), these more global units come to dominate processing (Ghim & Eimas, 1988; Navon, 1977). However, information gained in the early analysis of elements is not lost and may be accessed if task demands require it; it remains in the representation but is not salient. Perhaps accompanying the grouping operation responsible for constructing the organized whole, there is a reversible operation that allows direct access back to the element level.

With an unorganized array, the input to the perceptual system is not sufficiently structured to allow the grouping algorithm to begin its routine. The result is that element information may be processed less completely. Further processing may still yield a wholistic representation but one that may be less likely to contain information about where to look for an appropriate component part and therefore less able to direct access back to the element level. This tentative account of infant and adult results thus places important emphasis on a grouping algorithm that requires early processing of element information (e.g., brightness, color, size, orientation, location) to compile the higher order units that are so salient in perception (cf. Quinn & Eimas, 1986).

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