Perception, 1993, volume 22, pages 1483-1501

Gestalt relations and object perception: a developmental study

Elizabeth S Spelke, Karen Breinlinger, Kristen Jacobson, Ann Phillips
Department of Psychology, Cornell University, Uris Hall, Ithaca, NY 14853, USA
Received 14 January 1993, in revised form 22 May 1993

Abstract. We investigated whether adults and infants aged 3, 5, and 9 months perceive the unity and boundaries of visible objects in accord with the Gestalt relations of color and texture similarity, good continuation, or good form. Adults and infants were presented with simple but unfamiliar displays in which all three Gestalt relations specified either one object or two objects—perception of the objects was assessed by a verbal rating method in the adults and by a preferential looking method in the infants. The Gestalt relations appeared to influence the adults' perceptions strongly. However, the relations appeared to have no effect on the perceptions of 3-month-old infants and weak effects on the perceptions of 5-month-old and 9-month-old infants. The findings support the suggestion that developmental changes in object perception occur slowly. These changes, and the organizational phenomena to which Gestalt psychology called attention, may depend in part on the child's developing ability to recognize objects of particular kinds.

1 Introduction

1.1 *Gestalt relations and object perception in infancy*

Research on object perception suggests a notable difference between the perceptions of young infants and those of older children and adults. Adults perceive the unity and boundaries of objects, in part, by analyzing the colors, textures, and shapes of surfaces so as to form units that are maximally simple and homogeneous (eg Koffka 1935; Wertheimer 1923/1958). Children as young as 2 years also organize visual scenes into simple homogeneous units (Schmidt 1985). In contrast, 3-month-old and 4-month-old infants have not been found to exhibit this tendency, even though infants detect properties of surfaces such as color (eg Teller and Bornstein 1987), texture (eg Meltzoff and Borton 1979), and edge alignment (eg van Giffen and Haith 1984), and infants perceive the unity and boundaries of objects by analyzing spatial and kinematic relations among surfaces (Kellman 1993; Spelke 1990). In the language of Gestalt psychology, young infants appear to perceive objects in accord with the relation of common fate but not the relations of similarity, good continuation, or good form.

Infants' failure to perceive objects in accord with the latter Gestalt relations is suggested by their responses to three situations. First, infants aged 3 and 5 months have been presented with two adjacent objects of contrasting colors, textures, and shapes, arranged so that the edges of the objects were not aligned (eg figure 1a). When the objects underwent distinct motions, patterns of preferential looking and reaching provided evidence that infants perceived the objects as two distinct units. When the objects were stationary or moved together, in contrast, the same measures provided evidence that infants perceived the objects as a single unit (Hofsten and Spelke 1985; Kestenbaum et al 1987; Spelke et al 1989). For infants, the relations of similarity, good continuation, and good form do not appear to specify the boundaries of adjacent objects.

Second, 4-month-old infants have been presented with an object whose top and bottom were visible but whose center was occluded. When the ends of the object were aligned and uniformly coloured and underwent a common motion (eg figure 1b), patterns of preferential looking provided evidence that infants perceived the object as a unit that was connected behind the occluder (Kellman and Spelke 1983; Kellman et al 1986; Slater et al 1990). In contrast to adults, however, infants' perception of object unity appeared to be equally strong when the commonly moving ends of the objects differed in color and texture, were misaligned, and combined to form an irregular shape (Kellman and Spelke 1983; see figure 1c). When the ends of a homogeneous and symmetrical object moved together, moreover, infants did not appear to extrapolate a simple and regular connection between those ends in preference to a more complex connection (Craton and Baillargeon, in preparation). Finally, when the ends of a homogeneous and symmetrical object were stationary, infants' perception appeared to be indeterminate between that of a unitary connected object and that of two distinct objects separated by a gap (Kellman and Spelke 1983; Schmidt and Spelke 1984; Schwartz 1982). For young infants, the relations of color and texture similarity, good continuation, and good form do not appear to specify the unity or shape of a partly hidden object.

Third, infants have been presented with two-dimensional (2-D) displays that for adults elicit an impression of illusory contours. When an illusory form or contour was specified by motion, looking patterns and reaching patterns both provided evidence that 3-month-old and 5-month-old infants perceived it (Kaufmann-Hayoz et al 1986; Yonas and Granrud 1985; see also Bertenthal et al 1987). In contrast, when an illusory form was specified by the static Gestalt relations among its inducing elements (figure 1d), preferential looking patterns provided evidence that the pattern was perceived at 7 months but not at 5 months (Bertenthal et al 1980). Infants under 6 months do not appear to perceive illusory contours specified by the relations of good continuation and good form.

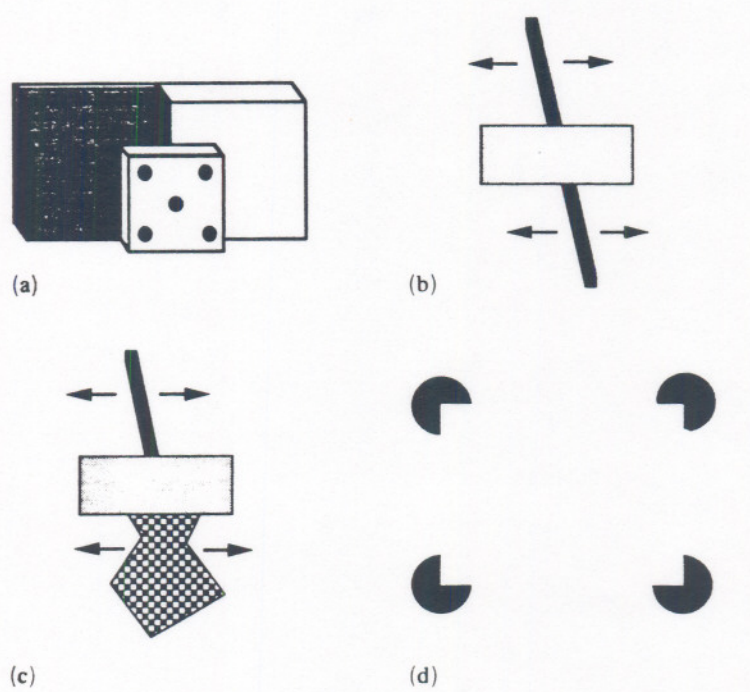


Figure 1. Schematic depiction of the displays presented in studies of infants' perception of objects. Arrows indicate the direction of motion. After (a) Kestenbaum et al (1987), (b) and (c) Kellman and Spelke (1983), and (d) Bertenthal et al (1980).

The convergence among these studies is striking, given the variety of displays and methods that have been employed in the different studies. Moreover, the negative findings from studies of sensitivity to static Gestalt relations contrast with the positive evidence, from studies in which the same methods have been used at the same ages, for sensitivity to kinematic relations specifying object boundaries. This contrast suggests that the negative findings do not stem from general inadequacies of the experimental methods or a general inability of infants to perceive objects or 2-D forms. Rather, young infants appear to be insensitive to static configurational information for object unity and boundaries [see Kellman (1993) and Spelke (1990) for discussion].

When, and through what developmental sequence, do infants come to perceive objects in accord with static Gestalt relations? The question is of interest for two reasons. First, studies of developmental changes in object perception may shed light on a variety of other developing abilities that depend in part on object representations, including reaching and manipulation (eg Hofsten 1991; Streri 1991), physical reasoning (eg Baillargeon 1993), counting (eg Shipley and Shepperson 1990), and the acquisition of language (eg Markman 1989). Second, studies of developmental changes in object perception may shed light on the processes by which adults perceive objects and on the nature of the Gestalt organizational phenomena observed at older ages.

1.2 *The nature of Gestalt phenomena*

The representations and processes underlying object perception have been debated from the early days of Gestalt psychology (eg Wertheimer 1923/1958) to the present time (eg Kanizsa 1979; Marr 1982; Witkin and Tenenbaum 1983). Some have proposed that perceptual organization depends on a single rule or principle whose function is variously characterized as maximizing the 'goodness' of a scene (eg Koffka 1935) or minimizing the amount of information the scene contains (eg Hatfield and Epstein 1985; Hochberg and McAlister 1953). Others have proposed that each Gestalt principle of organization reflects the operation of a separate rule (eg Brunswik and Kamiya 1953; see also Helmholtz 1909/1962; Kellman and Shipley 1991). Both types of rule-based accounts contrast with the view that object perception depends on processes of object recognition. According to Marr (1982), processes prior to object recognition serve to construct representations of the continuous surface layout but do not divide the layout into objects. Object perception depends on the recognition, within the layout, of objects of familiar kinds. On a recognition-based view, Gestalt effects on object perception might be produced by the object-recognition process, because many of the objects in modern environments have relatively homogeneous substances, smooth edges, and simple shapes.[1] For example, adults may perceive the forms in figure 1, not by applying general rules of organization, but by recognizing each form as a 'block', a 'stick', or a 'disc', and they may perceive unfamiliar forms by analogy with familiar objects.[2]

These proposals may be distinguished by studies of developmental changes in infants' perception of objects. If mature object perception depends on a single propensity to maximize figural goodness or to minimize information, then there

[1] Gestalt effects also may occur earlier in visual analysis: For example, they may enter into the representation of intensity edges in the 2-D visual image, the segregation of visual arrays into regions of uniform texture, or the reconstruction of surfaces in the 2.5-D layout. These processes are probably distinct from the processes underlying object perception and are not discussed here.

[2] Huttenlocher (1990) and Ullman (1989) propose mechanisms for recognizing objects in an unparsed visual array.

should be a single time in development when this propensity emerges. All the Gestalt relations should become effective at once, and they should specify the boundaries of unfamiliar, as well as familiar, objects. If object perception depends on a collection of separate rules, then sensitivity to different Gestalt relations might emerge at different times in development. As soon as one relation become effective, it should specify the boundaries both of unfamiliar and of familiar objects. Finally, if object perception depends on object recognition, then Gestalt relations should come to influence object perception slowly, with high variability across infants and displays. Variability should be especially high when infants are presented with displays containing unfamiliar objects because such displays may evoke representations of different familiar objects for different infants. Although there is likely to be considerable overlap among the sets of objects that different infants recognize, these sets are not likely to be identical. Each infant, therefore, may approach a new unfamiliar object with a somewhat different 'vocabulary' of familiar objects on which to draw.

In the present experiments we investigated infants' perception of three-dimensional (3-D) displays whose shapes were simple but (most likely) unfamiliar. For these displays, the Gestalt relations of similarity, good continuation, and good form either specified one connected object (figure 2a) or two distinct objects (figure 2b). Adults' perception of the displays was tested first, in order to ensure that each display gave rise to a clear perception of object unity and boundaries. The perception, by 3-month-old infants, of object boundaries was tested next, because previous research suggested no effect of static Gestalt relations at that age. Finally, infants' perception was tested at 5 and 9 months of age, because research using a potentially familiar form (a rectangle) provided evidence that static Gestalt relations have come to influence object perception by 7 months (Bertenthal et al 1980). If this influence depends on the development of one or more general rules or principles, then development changes should be observed between 5 and 9 months for unfamiliar as well as familiar forms.

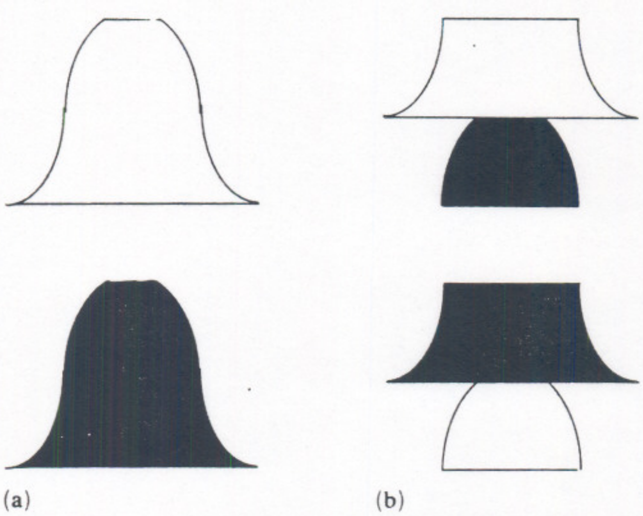


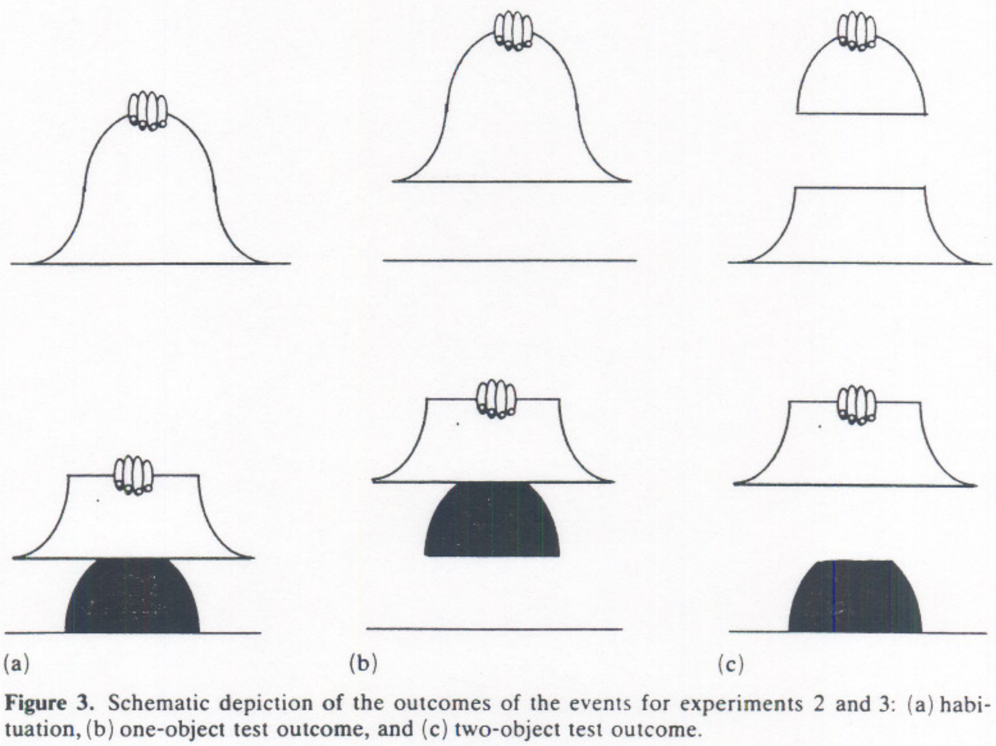
Figure 2. Schematic depiction of the displays for the present experiments: (a) homogeneous displays and (b) heterogeneous displays.

1.3 *The cohesion principle*

We investigated infants' perception of objects by assessing their reactions to events that violate the 'cohesion principle'. According to this principle, freely moving objects maintain their connectedness and their boundaries: they neither break apart nor coalesce with other bodies. The cohesion principle appears to guide infants' perception of visible objects (Spelke 1990; Spelke and Van de Walle 1993). For example, patterns of preferential looking and of object-directed reaching provide evidence that at 3 to 5 months of age infants perceive an array of stationary adjacent surfaces as a connected body that will maintain its connectedness over motion, and that such infants perceive two arrays of surfaces separated by a gap as distinct bodies that will move independently (Hofsten and Spelke 1985; Kestenbaum et al 1987; Spelke et al 1989; see also Spelke and Born 1982 cited in Spelke 1988). Both findings accord with the principle that moving objects maintain their connectness and their boundaries.

Further research provides evidence that the cohesion principle guides infants' reasoning about hidden objects (Carey et al 1992). Infants who were 8 months old were presented with events in which one object moved in and out of view behind a screen, such that it disappeared successively at two locations, and then the screen was removed to reveal one body (consistent with the cohesion principle) or two bodies (inconsistent with that principle). Looking times to these outcomes were compared, on the assumption that infants would look longer at the inconsistent event outcome if they detected its inconsistency [see Leslie (1991), Spelke et al (1992), Wynn (1992), and Xu and Carey (1992) for evidence that supports this assumption; see also Baillargeon (1993) for a review of complementary evidence from studies in which a different preferential looking method was used]. Although controls within the experiments revealed that the inconsistent outcome was not more attractive in itself, infants looked longer at that outcome. The experiment provides evidence that 8-month-old infants infer that hidden objects will move as connected bodies, in accord with the cohesion principle.

In the present experiments we used a preferential looking method similar to that of Carey et al (1992) to assess infants' reactions to the outcomes of fully visible events that either accord with, or violate, the cohesion principle (figure 3). Infants first were



(a) (b) (c)

Figure 3. Schematic depiction of the outcomes of the events for experiments 2 and 3: (a) habituation, (b) one-object test outcome, and (c) two-object test outcome.

presented with a stationary display on the floor of an otherwise-empty stage. In one experimental condition (homogeneous), the relations of good continuation, good form, and color similarity specified that the display consisted of one object. In a second experimental condition (heterogeneous), the same relations specified two adjacent, vertically arranged objects. After familiarization with the display, infants were shown test events in which a hand entered the stage, grasped the top of the display, and lifted it. In one event, the whole display rose into the air (one-object outcome). In the other event, the top half of the display rose into the air while the bottom half remained at rest (two-object outcome). Looking times to the two outcomes were compared with the looking times of infants in a baseline condition, who viewed the same outcomes with no prior exposure to the display or the lifting events. If infants perceive objects in accord with the cohesion principle but not in accord with the Gestalt relations of color similarity, good continuation, or good form, then the infants in both experimental conditions should look longer at the two-object outcome, relative to the infants in the baseline condition. In contrast, if infants perceive objects in accord both with the cohesion principle and with the Gestalt principles of similarity, good continuation, and good form, the above pattern should be stronger for the infants presented with the homogeneous display. Indeed, the infants presented with the heterogeneous display might look longer at the one-object outcome, because lifting the top of the display would cause its bottom to rise only if the display consisted of one connected body.

2 Experiment 1

In the first experiment we investigated how adults perceived the displays which were to be presented to infants and how the adults reasoned about the possible motions of the displays. Each subject was presented in succession with the four displays in figure 2. After viewing a display, he or she was asked (a) how many objects the display appeared to contain, (b) whether the top of the display appeared to be connected to the bottom of the display, and (c) whether the bottom of the display would rise into the air if the top of the display were grasped and lifted.

2.1 *Method*

2.1.1 *Subjects*. Participants were two male and ten female students or employees at Cornell University, ranging in age from 16 to 34 years (mean age 21 years). No subject had taken a course in perception or had any knowledge of the present research with infants.

2.1.2 *Displays and apparatus*. All the displays were made of concentric circles of foam core, stacked and pasted together, painted red or blue, and covered with gold or silver metallic stars. The concentric circles increased from 6 cm to 23 cm in diameter in steps of 5 mm. When stacked to form an object, they were 17.5 cm in height. Each display was presented on a white surface against a white background. A white screen covered the presentation area between trials, allowing the displays to be changed out of the subject's view. A subject viewed the displays while seated at a distance of about 90 cm. A cardboard depiction of a 7-point scale, marked from "1: very weak" to "7: very strong", stood on the left side of the table throughout the experiment.

2.1.3 *Design*. Each subject viewed each of the four displays once. The homogeneous and heterogeneous displays were presented in alternation, such that the homogeneous display appeared first for half the subjects. Half the subjects in each presentation order saw the red display before the blue display, and half saw the red-topped display before the blue-topped display.

2.1.4 *Procedure*. Before the start of the study, subjects were told that we were interested in their immediate impressions of the displays we were to present to infants. In order to ensure that subjects understood the questions to be presented, there were then 2 pretest trials. Subjects were shown the rating scale and an empty coffee mug on the table, and they were asked the following series of questions: "How many objects do you see?" (All subjects reported one object.) "How strong is your impression of one object on this scale, where '1' means a very weak impression of one object and '7' means a very strong impression of one object?" [Subjects' mean rating (M) was 6.75]. "Does this (pointing to the handle of the mug) appear to be connected to this (pointing to the bowl of the mug)?" (All subjects said "yes".) "How strong is your impression of a connection on this scale?" (M = 6.92.) "If I were to grasp this (pointing to the handle of the mug without touching it) and lift it from here (still pointing to the handle) to here (raising the pointed finger to a position about 34 cm above its initial position), what would happen to this (pointing to the bowl of the mug)?" (All subjects said the bowl would move with the handle.) "How strong is your impression that it will move?" (M = 7.0.) Next, subjects were presented with the same coffee mug containing a spoon. The same questions were asked, accompanied by pointing to the spoon and to the bowl of the mug. All the subjects reported a strong impression of two objects (M = 6.58), a strong impression that the spoon was not connected to the bowl (M = 6.75), and a strong impression that the bowl would remain on the table if the spoon were lifted (M = 7.00). Subjects received no feedback on their responses to the warm-up trials. The experiment was then immediately conducted.

The experimenter lowered the screen, positioned the first display behind it, and raised the screen. After the subject had viewed the display for about 5 s, the experimenter asked the same sequence of questions. For the connectedness question, she pointed first to the top of the display and then to the bottom of the display. For the common-movability question, she pointed first to the display top, then to a position about 34 cm above the display top, and then to the display bottom.

2.1.5 *Analyses*. Subjects' ratings of the number, connectedness, and common movability of the objects were converted to a single scale from +7 (strong impression of one object/connectedness/common movability) to −7 (strong impression of two objects/separateness/independent movability). For each question and each display, the ratings were tested against the neutral value of 0 by a two-tailed t test. In addition, the ratings of different displays were compared with one another by a 2 (display: homogeneous versus heterogeneous) by 2 (order: homogeneous first versus heterogeneous first) analysis of variance.

2.2 *Results*

Table 1 presents the mean ratings for each of the three questions. For the number-of-objects question, each homogeneous display was judged to contain one object (t = 14.00 and 18.42, $p < 0.001$), and each heterogeneous display was judged to contain two objects ($t = -4.79$, $p < 0.001$, and $t = -3.70$, $p < 0.005$). The display factor produced the only significant effect in the analysis of variance, $F_{1,10} = 90.39$, $p < 0.001$.

Table 1. Mean and standard deviation (shown in parentheses) of ratings of the number, connectedness, and common movability of the homogeneous and heterogeneous displays in experiment 1.

Display	Number	Connectedness	Movability
Homogeneous	5.88 (1.26)	3.88 (4.43)	3.96 (4.43)
Heterogeneous	−4.59 (3.71)	−5.18 (2.67)	−5.46 (2.65)

For the connectedness question, the homogeneous displays were judged to have connected tops and bottoms ($t = 4.13$, $p < 0.001$, and $t = 2.19$, $p < 0.05$), whereas the heterogeneous displays were judged to have unconnected tops and bottoms ($t = -4.86$ and -14.68, $p < 0.001$). The analysis of variance revealed only this effect of display, $F_{1,10} = 90.93$, $p < 0.001$.

For the common-movability question, the bottom of each homogeneous display was predicted to move with the top of the display ($t = 4.23$, $p < 0.001$, and $t = 2.24$, $p < 0.025$), whereas the bottom of each heterogeneous display was predicted to remain on the table ($t = -4.99$ and -15.46, $p < 0.001$). The display factor produced the only significant effect in the analysis of variance, $F_{1,10} = 91.27, p < 0.001$.

2.3 *Discussion*

Adults' verbal ratings provided evidence that they perceived each homogeneous display as one connected object and each heterogeneous display as two unconnected objects. The differences in judgments concerning the homogeneous and heterogeneous displays were pronounced, providing evidence for a strong effect of Gestalt relations on adults' perception. Finally, subjects judged that each perceived object would move as a connected whole, independently of other objects, in accord with the cohesion principle. In the next experiment we investigated 3-month-old infants' perception of the same displays, by assessing infants' reactions to visible events presenting the patterns of motion that were described to adults.

3 Experiment 2

3.1 *Method*

3.1.1 *Subjects*. Participants were forty-eight infants (twenty-two girls and twenty-six boys) ranging in age from 2 months and 15 days to 3 months and 13 days (mean age 2 months and 29 days). Infants were born of full-term pregnancies, were apparently in good health, and resided in or near Ithaca, NY. Seven additional infants were eliminated from the experiment because of experimental error (1), computer failure (2), or fussiness (4).

3.1.2 *Displays, apparatus, and events*. The experiment took place within a 81 cm × 102 cm × 30 cm stage with white walls and a white floor, illuminated by two vertical 22 in fluorescent bulbs in the left and right front corners. Between trials, a white 40 cm × 100 cm screen was lowered to cover the center of the stage, occluding the display. Infants viewed the events from a reclinable seat at a distance of 50 cm from the center of the display. Curtains running to the left and right of the stage concealed two observers, who viewed the infant through peepholes. Observers could not see the displays from these points of observation.

The displays were the same as in experiment 1 (see figure 2). From the infant's point of observation, these displays subtended 18.9 deg in height, 25.9 deg in maximum width, and 6.9 deg in minimum width. Two versions of each display were created for the experiment. In one version, all the concentric circles comprising a display were glued together to form one connected body (the 'connected display'). In the other version, only the concentric circles on the top and on the bottom halves of the display were glued together, to form two bodies that were not connected to each other (the 'separated display'). When the two halves of a separated display were positioned as in figure 2, adults reported them to be indistinguishable from the corresponding connected display. The concentric circles on each display were visible to adults but inconspicuous.

Three events were shown to the infants in the two experimental conditions (see figure 3). In the familiarization event, the screen was raised to reveal one display on the stage floor, and a hand came to rest on its top. In the one-object test event, the screen was raised to reveal a connected display that looked identical to the familiarization display on the stage floor, and the hand grasped its top and lifted the whole display 8 cm into the air. In the two-object test event, the screen was raised to reveal a separated display that looked identical to the familiarization display on the stage floor, and the hand grasped its top and lifted the top half of the display 8 cm into the air. Two stationary test displays were shown to the infants in the baseline condition, corresponding to the outcomes in the above test events. In the one-object display, the screen was raised to reveal the hand holding the entire display in midair; in the two-object display, the screen was raised to reveal the hand holding the top half of the display in midair above the bottom half of the display.

3.1.3 *Design*. Equal numbers of subjects were tested in the homogeneous experimental condition, the heterogeneous experimental condition, and the baseline condition. Infants were assigned to these conditions quasi-randomly, so as to balance the sex and age distributions of the different conditions. In each experimental condition, half the infants were presented with each of the two displays (the red or blue homogeneous display; the red-topped or blue-topped heterogeneous display). Half the infants tested with each display were familiarized with a connected display and half with a separated display. After familiarization, the one-object and two-object test events were presented in alternation, with their order counterbalanced across the infants within each familiarization condition.

In the baseline condition, infants received one test sequence with a homogeneous display and one test sequence with a heterogeneous display. Half the infants were presented with the red homogeneous display and the blue-topped heterogeneous display: half were presented with the other two displays. The order of the test sequences (homogeneous first versus heterogeneous first) and the order of the displays within a sequence were counterbalanced across infants.

3.1.4 *Procedure*. In the experimental conditions, the study began when the screen was raised to reveal a display on the stage floor. The experimenter's right hand entered the stage, tapped three times on the top of the display, and came to rest. Looking time began to be recorded as soon as the hand came to rest and continued until the infant looked away from the display for 2 s continuously. Looking time was recorded by two observers operating push-button inputs to a microprocessor, which signalled the end of the trial with a tone. (Interobserver agreement, calculated as the proportion of seconds in which both observers judged that an infant was or was not looking at the display, averaged 0.86.) At that time, the screen was lowered and raised again 1 s later, beginning the next trial.

Trials continued until the infant met a criterion of habituation or until 14 trials were presented, whichever came first. The criterion of habituation was a 50% decline in looking time during 3 consecutive trials, relative to the first 3 trials on which the total looking time exceeded 12 s (usually the first 3 trials). The habituation criterion was calculated by the microprocessor, which generated a second tone to signal the end of the familiarization sequence.

The 6 test trials were then immediately conducted. On the one-object trials, the screen was raised to reveal the connected version of the display at the familiar position on the floor. The presenter's right hand entered the stage, tapped on the top of the display, grasped the top of the display, and lifted the display into the air. When her hand stopped moving, the presenter signalled the observers to begin recording looking time. On the two-object trials, the screen was raised to reveal the separated version of the display at the familiar position. The presenter's actions were the same, but only the top half of the display rose into the air. For both test trials, looking time was recorded beginning when the infant first looked at any position that the display could occupy on either type of test trial (observers were not informed of the test trial order for any given subject) and ending when the infant looked away from the display for 2 s. At the end of a trial, on a signal from the microprocessor, the screen was lowered. It was raised 2 s later to reveal the next display.

In the baseline condition, infants were presented with the test-trial outcomes viewed by the infants in the two experimental conditions. On each of 12 trials, the screen was raised to reveal a hand-held display in the air. On one-object trials, infants viewed a whole object held in the air; on two-object trials, they viewed the top half of a display held in the air above the bottom half of the display which rested on the stage floor. Each infant was tested with one homogeneous display and one heterogeneous display on 6 consecutive trials. Looking time was recorded as in the experimental condition.

3.1.5 *Analyses*. The looking-to-event-outcomes method produces looking times with highly irregular distributions, in violation of the assumptions of general linear models (Darlington 1990). Accordingly, nonparametric statistics were used as the principal analyses. For each infant and each condition, the proportion of total test-trial looking time to the two-object display was calculated: a measure of that infant's preference for the two-object outcome. These preferences were analyzed by Wilcoxon signed-ranks tests. In addition, the preferences of infants in different conditions were compared by Wilcoxon-Mann-Whitney tests (Siegel and Castellan 1988).

3.2 *Results*

3.2.1 *Familiarization sequence*. During the first 3 familiarization trials, the mean looking time per trial was 18.9 s in the homogeneous condition and 17.6 s in the heterogeneous condition. Four infants in each condition did not meet the habituation criterion and were tested after 14 familiarization trials.

3.2.2 *Test sequence*. Table 2 presents the mean and median looking times at the one-object outcome and the two-object outcome and the proportion of looking at the two-object outcome for each condition of the experiment. The infants in each of the experimental conditions tended to look longer at the two-object outcome, whereas those in the baseline condition tended to show the opposite preference. Combining data from the homogeneous and the heterogeneous conditions, the infants in the experimental conditions showed a greater preference for the two-object outcome than did those in the baseline condition during the first baseline session, Wilcoxon-Mann-Whitney $z = 1.82$, $p < 0.05$, and during the second baseline session, Wilcoxon-Mann-Whitney $z = 1.83$, $p < 0.05$.

Table 2. Mean (M) and median (Md) duration of looking at the test outcomes, and proportion of looking at the two-object outcome in experiment 2.

Condition	One-object outcome		Two-object outcome		Proportion	
	M	Md	M	Md	M	Md
Homogeneous						
experimental	54.4	35.1	62.0	47.0	0.507	0.477
baseline	32.9	21.4	26.4	16.8	0.438	0.407
Heterogeneous						
experimental	35.9	27.1	50.2	35.6	0.578	0.628
baseline	49.6	22.2	28.1	24.2	0.413	0.416
Conditions combined						
experimental	45.2	31.5	56.1	41.5	0.543	0.612
baseline (session 1)	45.3	18.2	25.3	10.3	0.421	0.399
baseline (session 2)	37.2	31.6	29.2	26.8	0.430	0.423

Preferences for the two-object outcome were no greater during the test session with homogeneous displays than during the test session with heterogeneous displays, either in the experimental condition (Wilcoxon-Mann-Whitney $z < 1$) or in the baseline condition (Wilcoxon $z < 1$). Because these analyses suggested no effect of static Gestalt relations on object perception, a final analysis focused separately on infants' perception of the heterogeneous displays. The preference for the two-object outcome was reliably higher in the heterogeneous experimental condition than in the baseline condition, Wilcoxon-Mann-Whitney $z = 2.25$, $p < 0.03$, two-tailed.

3.3 *Discussion*

After familiarization, either with a homogeneous or with a heterogeneous display, 3-month-old infants looked longer at the outcome of an event in which the display broke apart than at the outcome of an event in which the display moved as a whole. This preference is not attributable to the greater intrinsic attractiveness of the former event outcome, because it was not shown by infants in the baseline condition. The experiment therefore provides evidence that infants perceived each display as a connected body, in accord with the cohesion principle and consistent with the findings of past research (Hofsten and Spelke 1985; Kestenbaum et al 1987; Spelke et al 1989).

Reactions to the breakup of a display were no greater for the infants who viewed a display of a uniform color and shape than for the infants who viewed a display with a sharp discontinuity in color and shape at the point where the breakup occurred. Infants appeared to perceive each heterogeneous display as one object, contrary to the Gestalt principles of similarity, good continuation, and good form. Infants' apparent failure to perceive the displays in accord with these Gestalt relations accords with the findings of previous studies of object perception in which other preferential looking and reaching methods were used (eg Craton and Baillargeon in preparation; Kellman and Spelke 1983; Kestenbaum et al 1987).

Finally, the experiment provides evidence that infants respond with reliably increased looking when a perceived object breaks apart. This looking preference suggests that 3-month-old infants expect, at some level, that moving objects will maintain their connectedness, in accord with the cohesion principle.

4 Experiment 3

In the next experiment we used the method of experiment 2 to investigate developmental changes in object perception. The homogeneous and heterogeneous displays were presented to infants at 5 and at 9 months of age, and looking preferences at these ages were compared with one another and with the looking preferences of the 3-month-old infants in experiment 2.

4.1 *Method*

Participants were ninety-six infants. In the younger age group, the twenty-four boys and twenty-four girls ranged in age from 4 months and 15 days to 5 months and 15 days (mean age = 5 months and 1 day). One additional 5-month-old infant was eliminated from the study because of computer failure. In the older age group twenty-six boys and twenty-two girls ranged in age from 8 months and 15 days to 9 months and 14 days (mean age = 9 months and 0 days). Eight additional 9-month-old infants were eliminated from the study because of experimental error (2), parent interference (2), or fussiness (4). Interobserver reliability averaged 0.87 for infants in each age group.

4.2 *Results*

4.2.1 *Familiarization sequence*. For the 5-month-old infants, mean looking time per trial on the first 3 familiarization trials was 6.2 s in the homogeneous condition and

7.8 s in the heterogeneous condition, and the mean number of familiarization trials was 10.1 (homogeneous) and 9.4 (heterogeneous). For the 9-month-old infants, mean looking time on the first 3 familiarization trials was 4.2 s (homogeneous) and 4.2 s (heterogeneous), and the mean number of familiarization trials was 11 (homogeneous) and 10.6 (heterogeneous).

4.2.2 *Combined analyses of the test-sequence looking patterns at 5 and 9 months*. Table 3 presents the mean and median looking times at the one-object outcome and the two-object outcome and the mean proportion of looking at the two-object outcome for each age and condition of the experiment. When the 5-month-old and 9-month-old infants were treated as a single group and the data from the homogeneous and heterogeneous conditions were combined, the preference for the two-object outcome was no greater in the two experimental conditions than in the baseline condition, either during the first or during the second baseline session; each Wilcoxon-Mann-Whitney $z < 1$.

Analyses comparing the looking preferences of the infants presented with homogeneous versus heterogeneous displays revealed a significant effect of static Gestalt relations. The infants in the homogeneous experimental condition showed a reliably greater preference for the two-object outcome than did the infants in the heterogeneous

Table 3. Mean (M) and median (Md) duration of looking at the test outcomes and proportion of looking at the two-object outcome in experiment 3.

Condition	One-object outcome		Two-object outcome		Proportion	
	M	Md	M	Md	M	Md
Homogeneous						
experimental						
5 months	25.6	16.4	28.7	16.9	0.527	0.515
9 months	25.8	21.2	36.4	30.5	0.584	0.566
ages combined	25.7	18.4	32.6	25.2	0.555	0.558
baseline						
5 months	17.1	13.8	27.3	16.4	0.587	0.626
9 months	19.7	18.4	19.6	19.8	0.493	0.518
ages combined	18.4	15.5	23.4	17.4	0.540	0.542
Heterogeneous						
experimental						
5 months	32.8	27.4	25.7	18.5	0.439	0.423
9 months	32.6	25.4	36.9	34.0	0.527	0.486
ages combined	32.7	26.2	31.3	26.2	0.483	0.451
baseline						
5 months	27.2	14.4	31.5	21.9	0.526	0.494
9 months	20.2	16.6	22.1	17.8	0.536	0.552
ages combined	23.6	15.8	26.8	19.1	0.531	0.510
Conditions combined						
experimental						
5 months	29.2	21.1	27.2	17.6	0.483	0.451
9 months	29.2	22.4	36.6	32.6	0.555	0.550
ages combined	29.2	21.8	31.9	25.6	0.519	0.510
baseline (session 1)						
5 months	18.2	14.4	31.5	19.2	0.587	0.636
9 months	21.3	15.8	23.2	21.2	0.527	0.550
ages combined	19.8	14.8	27.4	20.2	0.557	0.586
baseline (session 2)						
5 months	26.2	14.8	27.2	17.0	0.526	0.470
9 months	18.6	18.6	18.5	15.0	0.503	0.506
ages combined	22.4	17.6	22.9	15.8	0.514	0.497

experimental condition, Wilcoxon-Mann-Whitney $z = 1.95$, $p < 0.05$. In contrast, the infants in the baseline condition showed no greater preference for the two-object outcome during the session with homogeneous objects, Wilcoxon $z < 1$.

The effects of static Gestalt relations were analyzed in more detail by focusing separately on each experimental condition. Whereas the infants in the homogeneous condition looked reliably longer at the two-object outcome than at the one-object outcome, Wilcoxon $z = 2.25$, $p < 0.02$, the infants in the heterogeneous condition showed no preference between the two outcomes, Wilcoxon $z < 1$. The infants in the baseline condition also showed no preference between the two outcomes for either set of displays, each Wilcoxon $z < 1$.

4.2.3 *Looking patterns at 5 months*. When the data from the 5-month-old infants in the two experimental conditions were combined, the infants showed a marginal preference for the two-object outcome compared with the first session of the baseline condition, Wilcoxon-Mann-Whitney $z = 1.88$, $p < 0.10$, although not compared with the second session of the baseline condition, $z < 1$. The preference for the two-object outcome was marginally greater in the homogeneous experimental condition than in the heterogeneous experimental condition, Wilcoxon-Mann-Whitney $z = 1.43$, $p < 0.10$. In the baseline condition, preferences between the two outcomes did not differ across the sessions with homogeneous versus heterogeneous displays, Wilcoxon $z < 1$.

4.2.4 *Looking patterns at 9 months*. When the data from the 9-month-old infants in the two experimental conditions were combined, they revealed no preference for the two-object outcome, relative either to the first or to the second session of the baseline condition, Wilcoxon-Mann-Whitney $z < 1$ and $z = 1.07$, respectively. Although the preference for the two-object outcome tended to be greater in the homogeneous experimental condition than in the heterogeneous experimental condition, this difference was not significant, Wilcoxon-Mann-Whitney $z = 1.17$. Preferences between the two outcomes also did not differ across the baseline sessions with homogeneous versus heterogeneous objects, Wilcoxon $z < 1$.

4.2.5 *Developmental changes in looking patterns*. The test-trial data from experiments 2 and 3 were further analyzed to assess age differences in infants' reactions to the homogeneous and heterogeneous displays. In the homogeneous experimental condition, no change in preferences occurred between 3 and 5 months or between 5 and 9 months, Wilcoxon-Mann-Whitney $z < 1$ and $z = 1.23$, respectively. In the baseline session with homogeneous displays, the preference for the two-object outcome showed a marginally significant increase from 3 to 5 months, Wilcoxon $z = 1.94$, $p < 0.10$, and a nonsignificant decrease from 5 to 9 months, Wilcoxon $z = 1.45$.

In the heterogeneous experimental condition, there was a significant decline in preference for the two-object outcome from 3 to 5 months, Wilcoxon-Mann-Whitney $z = 1.92$, $p < 0.05$, and no significant change in preferences from 5 to 9 months, Wilcoxon-Mann-Whitney $z = -1.42$. In the baseline session with heterogeneous displays, in contrast, there was a marginally significant increase in preference for the two-object outcome from 3 and 5 months, Wilcoxon $z = -1.97$, $p < 0.10$, and no further change from 5 to 9 months, Wilcoxon $z < 1$.

4.3 *Discussion*

The findings of experiment 3 provide evidence that 5-month-old and 9-month-old infants' perception of objects is influenced by static Gestalt relations. As a group, these infants showed a reliably greater preference for the event outcome in which the homogeneous display broke apart than for the event outcome in which the heterogeneous display broke apart. This difference in preferences cannot be attributed to differences in the intrinsic attractiveness of the outcomes, because it was not shown by the infants in the baseline condition. Because the homogeneous and heterogeneous displays were constructed from the same components, the primary differences between them concerned their static Gestalt properties: the relations of similarity, good continuation, and good form specified that the homogeneous display consisted of one object and that the heterogeneous display consisted of two objects. Infants at 5 and 9 months of age appear to perceive objects, in part, by analyzing these Gestalt relations.

Nevertheless, the weakness of the present findings is striking in two respects. First, the infants in the heterogeneous experimental condition looked approximately equally as long at an event outcome in which a heterogeneous display broke part as they did at an event outcome in which it moved as a whole. The experiment therefore provides no evidence that the infants perceived the heterogeneous displays to contain two objects, in accord with static Gestalt relations. Second, the difference between preferences in the homogeneous and heterogeneous conditions was not reliable, either at 5 months or at 9 months, when looking patterns at each age were analyzed separately. The absence of reliable findings at each age contrasts with the reliable effects of the cohesion principle for the 3-month-old infants in experiment 2. We return to this contrast in the general discussion.

The findings of experiments 2 and 3 shed light on developmental changes in object perception which occur from 3 to 9 months. Between 3, 5, and 9 months, no changes were evident in infants' reactions to the breakup of the homogeneous display. The lack of change is not surprising, given that static Gestalt relations and the cohesion principle both specify that the display consists of a single object. In contrast, a significant decline in reactions to the breakup of the heterogeneous display occurred between 3 and 5 months. This decline, which was not due to a change in baseline preferences, suggests that static Gestalt relations exert an increasing influence on infants' perception of objects between 3 and 5 months. Nevertheless, no further changes in reactions to the heterogeneous displays were observed between 5 and 9 months, even though 5-month-old infants' reactions were not strong or reliable. The ability to perceive objects in accord with Gestalt relations therefore appears to develop over an extended period of time.

5 General discussion

The present experiments shed light on developmental changes in object perception in infancy. At 3 months of age, object perception appears to accord with the cohesion principle but does not appear to be influenced by the Gestalt relations of similarity, good continuation, or good form. At 5 and 9 months, in contrast, object perception appears to be influenced by these Gestalt relations. Nevertheless, the effects of static Gestalt relations do not appear to be strong, either at 5 or at 9 months of age.

5.1 *The cohesion principle*

Like earlier research (Hofsten and Spelke 1985; Kestenbaum et al 1987; Spelke et al 1989), experiment 2 provides evidence that 3-month-old infants group surfaces into objects in accord with the cohesion principle. Presented with an array of adjacent surfaces, young infants appear to perceive one connected body that should maintain its connectedness as it moves. This finding suggests that the cohesion principle guides infants' perception of objects and infants' sensitivity to the transformations that objects can and cannot undergo.

In most previous studies of the cohesion principle, young infants were presented with objects of shapes which are frequently encountered, such as blocks and cylinders.

The findings of those experiments, therefore, were consistent with the possibility that young infants have learned to apply the cohesion principle to familiar objects but have not formed the broader generalization that the principle applies to all solid bodies. In experiment 2, in contrast, infants were presented with objects whose shapes were designed to be unfamiliar. The findings of that experiment therefore suggest that young infants apply the cohesion principle to a broad range of perceptible objects.

5.2 *Gestalt relations*

Whereas experiment 2 adds to the evidence against the thesis that the Gestalt relations of good continuation, good form, and similarity underlie humans' earliest perceptions of objects (eg Bertenthal et al 1980; Kellman and Spelke 1983; Kestenbaum et al 1987), experiment 3 adds to the evidence that object perception begins to be influenced by these relations over the course of the first year (Bertenthal et al 1980, Carton and Baillargeon in preparation; Schmidt 1985). Nevertheless, static Gestalt relations appeared to exert only weak influences on infants' perception of the present displays. Although direct comparisons between the perception of infants and adults are complicated by the different methods used to assess infants' and adults' perceptions, the findings of experiments 1–3 suggest that static Gestalt relations influenced object perception more strongly for adults than they did for infants.

Why did the relations of similarity, good continuation, and good form exert only weak effects on infants' perception of objects? One might suggest that the absence of any effect of these relations in experiment 2, and the weakness of their effects in experiment 3, stem from problems with the displays or the preferential looking method—perhaps the Gestalt relations in these displays were too subtle, the displays were too complex, or the method for assessing infants' perception was too insensitive. These possibilities are unlikely for several reasons. First, the displays appeared to evoke clear and strong perceptions of object boundaries for the adult subjects in experiment 1 who were tested by a different, verbal rating, method. Second, the Gestalt relations specifying object boundaries were defined by sharp changes in surface color and orientation. Because the objects were large, these changes should have been well within the limits of infants' sensitivity. Third, variations on the present method have revealed infants' sensitivity to a variety of principles governing object motion, at ages ranging from 2.5 to 10 months (Carey et al 1992; Leslie 1991; Spelke et al 1992; Wynn 1992; Xu and Carey 1992), and the present method itself revealed 3-month-old infants' sensitivity to the cohesion principle. Finally, the findings of the present experiments converge with the findings of other experiments in which different methods and measures have been used (including measures of preferential looking, object-directed reaching, and expressions of surprise) and in which a variety of objects with and without motion were presented (eg Carey et al 1992; Hofsten and Spelke 1985; Kellman and Spelke 1983; Kestenbaum et al 1987; Spelke 1988). One can never conclude with confidence that a given ability is weak or absent at a given age, because it is always possible that the ability would be revealed by new studies with the use of different methods or displays. Nevertheless, a plausible interpretation of the findings of existing studies is that Gestalt relations influence young infants' perception weakly at best, and that the developmental processes by which their influence increases occur gradually.

5.3 *Gestalt relations and object perception*

Studies of infant perception raise questions for any rule-based account of Gestalt organizational phenomena. First, why have static Gestalt relations not been found to exert any detectable effect on young infants' perception of objects? The absence of such an effect is puzzling in view of young infants' evident ability to detect Gestalt relations such as symmetry (Bornstein et al 1981), alignment (Schwartz and Day

Nishihara 1978). As children come to recognize increasing numbers of objects, therefore, their organization of visual scenes should gradually and increasingly accord with the Gestalt relations of similarity, good continuation, and good form.

This account would explain why static Gestalt relations appear to influence object perception more strongly when infants are presented with frequently encountered forms. Infants are more likely to have constructed representations of such forms, which therefore can be singled out by object-recognition processes. The account could also explain why high variability has been observed in studies presenting unfamiliar forms to infants. Unfamiliar forms may be reminiscent of different familiar objects for different infants, producing contrasting organizations of the same array.

Finally, the account could explain why static Gestalt relations come to influence object perception slowly over the course of development. Just as children take years to acquire the lexicon of their language, they may take years to acquire a mature vocabulary of object representations, each specific to one of the perceptibly different kinds of things that populate human environments.

To test this account of object perception, it would be desirable to probe more directly the development of object recognition. The processes by which humans recognize objects are quite poorly understood at any age, despite intense study within cognitive psychology (eg Biederman 1987), comparative psychology (eg Herrnstein 1984), and computer science (eg Ullman 1989). Because the ability to recognize most common objects probably develops during the first years, studies of early development may illuminate aspects of this ability. The present experimental method may be useful in this regard.

Acknowledgements. Supported by grants to ESS from NSF (BNS-8613390) and NIH (HD23103) and by a fellowship from the James McKeen Cattell Fund. We thank Peter Vishton, Amanda Woodward, and Suzanne Wurster for assistance and discussions.

References

Baillargeon R, 1993 "The object concept revisited: New directions in the investigation of infants' physical knowledge", in *Visual Perception and Cognition in Infancy* Ed. C R Granrud (Hillsdale, NJ: Lawrence Erlbaum)

Bertenthal B I, Campos J J, Haith M M, 1980 "Development of visual organization: The perception of subjective contours" *Child Development* **51** 1072 - 1080

Bertenthal B I, Proffitt D R, Kramer S J, 1987 "Perception of biomechanical motions by infants: Implementation of various processing constraints" *Journal of Experimental Psychology: Human Perception and Performance* **13** 577 - 585

Biederman I, 1987 "Recognition by components: A theory of human image understanding" *Psychological Review* **94** 115 - 117

Bornstein M, Ferdinandsen K, Gross C G, 1981 "Perception of symmetry in infancy" *Developmental Psychology* **17** 82 - 86

Brunswik E, Kamiya J, 1953 "Ecological cue-validity of "proximity" and of other gestalt factors" *American Journal of Psychology* **66** 20 - 32

Carey S, Klatt L, Schlaffer M, 1992 "Infants' representations of objects and nonsolid substances", unpublished manuscript, MIT (available from: S Carey, MIT, Department of Brain and Cognitive Sciences, E10-016, Cambridge, MA 02139)

Cohen L B, Younger B A, 1983 "Perceptual categorization in the infant", in *New Trends in Conceptual Representation* Ed. E Scholnick (Hillsdale, NJ: Lawrence Erlbaum)

Darlington R, 1990 *Regression and Linear Models* (New York: McGraw-Hill)

Granrud C E, Haake R J, Yonas A, 1985 "Infants' sensitivity to familiar size: The effect of memory on spatial perception" *Perception & Psychophysics* **37** 459 - 466

Hatfield G, Epstein W, 1985 "The status of the minimum principle in the theoretical analysis of visual perception" *Psychological Bulletin* **97** 155 - 186

Held R, Birch E E, Gwiazda J, 1980 "Stereoacuity of human infants" *Proceedings of the National Academy of Sciences (USA)* **77** 5572 - 5574

Helmholtz H von, 1909/1962 *Handbook of Physiological Optics* volume 3 (New York: Dover, 1962); English translation by J P C Southall for the Optical Society of America (1924) from the 3rd German edition of *Handbuch der Physiologischen Optik* (Hamburg: Voss, 1909)

Herrnstein R J, 1984 "Objects, categories, and discriminative stimuli", in *Animal Cognition* Eds H L Roitblat, T G Bever, H S Terrace (Hillsdale, NJ: Lawrence Erlbaum) pp 233 - 261

Hochberg J; McAlister E, 1953 "A quantitative approach to figural 'goodness'" *Journal of Experimental Psychology* **46** 361 - 364

Hoffman D D, Richards W A, 1984 "Parts of recognition" *Cognition* **18** 65 - 96

Hofsten C von, 1991 "Structuring of early reaching movements: A longitudinal study" *Journal of Motor Behavior* **23** 280 - 292

Hofsten C von, Spelke E S, 1985 "Object perception and object-directed reaching in infancy" *Journal of Experimental Psychology: General* **114** 198 - 212

Huttenlocher D P, 1990 "Recognizing solid objects by alignment with an image" *Journal of Computer Vision* **5** (2) 195 - 212

Kanizsa G, 1979 *Organization in Vision: Essays on Gestalt Perception* (New York: Praeger)
Kaufmann-Hayoz R, Kaufmann F, Stucki M, 1986 "Kinetic contours in infants' visual perception" *Child Development* **57** 53-58
Kellman P J, 1993 "Kinematic foundations of infant visual perception", in *Visual Perception and Cognition in Infancy* Ed. C Granrud (Hillsdale, NJ: Lawrence Erlbaum)
Kellman P J, Shipley T F, 1991 "A theory of visual interpolation in object perception" *Cognitive Psychology* **23** 141-221
Kellman P J, Spelke E S, 1983 "Perception of partly occluded objects in infancy" *Cognitive Psychology* **15** 483-524
Kellman P J, Spelke E S, Short K R, 1986 "Infant perception of object unity from translatory motion in depth and vertical translation" *Child Development* **57** 72-76
Kestenbaum R, Termine N, Spelke E S, 1987 "Perception of objects and object boundaries by three-month-old infants" *British Journal of Developmental Psychology* **5** 367-383
Koffka K, 1935 *Principles of Gestalt Psychology* (New York: Harcourt, Brace and World)
Leslie A M, 1991 "Infants' understanding of invisible displacement", paper presented at the biennial meetings of the Society for Research in Child Development, Seattle, WA (abstract)
Mandler J M, McDonough L, 1993 "Concept formation in infancy" *Cognitive Development* **8** 291-318
Markman E M, 1989 *Categorization and Naming in Children* (Cambridge, MA: Bradford/MIT Press)
Marr D, 1982 *Vision* (San Francisco, CA: W H Freeman)
Marr D, Nishihara H K, 1978 "Representation and recognition of the spatial organization of three-dimensional shapes" *Proceedings of the Royal Society of London Series B* **207** 269-294
Meltzoff A N, Borton R W, 1979 "Intermodal matching by human neonates" *Nature (London)* **282** 403-404
Ross G, 1980 "Categorization in 1- to 2-year olds" *Developmental Psychology* **16** 391-396
Schmidt H, 1985 *The Role of Gestalt Principles in Perceptual Completion: A Developmental Approach* unpublished doctoral dissertation, University of Pennsylvania, Philadelphia, PA
Schmidt H, Spelke E S, 1984 "Gestalt relations and object perception in infancy", paper presented at the biennial meetings of the International Conference on Infant Studies, New York, NY (abstract)
Schwartz K, 1982 *Perceptual Knowledge of the Human Face in Infancy* unpublished PhD thesis, University of Pennsylvania, Philadelphia, PA
Schwartz M, Day R H, 1979 "Visual shape perception in early infancy" *Monographs of the Society for Research in Child Development* **44** Serial No. 182
Shipley E F, Shepperson B, 1990 "Countable entities: Developmental changes" *Cognition* **34** 109-136
Siegel S, Castellan N J Jr, 1988 *Nonparametric Statistics for the Behavioral Sciences* 2nd edition (New York: McGraw-Hill)
Slater A, Morison V, Somers M, Mattock A, Brown E, Taylor D, 1990 "Newborn and older infants' perception of partly occluded objects" *Infant Behavior and Development* **13** 33-49
Spelke E S, 1988 "Where perceiving ends and thinking begins: The apprehension of objects in infancy", in *Perceptual Development in Infancy: The Minnesota Symposia on Child Psychology* volume 20, Ed. A Young (Hillsdale, NJ: Lawrence Erlbaum)
Spelke E S, 1990 "Principles of object perception" *Cognitive Science* **14** 29-56
Spelke E S, Breinlinger K, Macomber J, Jacobson K, 1992 "Origins of knowledge" *Psychological Review* **99** 605-632
Spelke E S, Hofsten C von, Kestenbaum R, 1989 "Object perception and object-directed reaching in infancy: Interaction of spatial and kinetic information for object boundaries" *Developmental Psychology* **25** 185-196
Spelke E S, Van de Walle G, 1993 "Perceiving and reasoning about objects: Insights from infants", in *Spatial Representation* Eds N Eilan, W Brewer, R McCarthy (New York: Basil Blackwell)
Streri A, 1991 *Voir, Atteindre, Toucher: Les Relations entre la Vision et le Toucher chez le Bébé* (Paris: Presses Universitaires de France)
Teller D Y, Bornstein M H, 1987 "Infant color vision and color perception", in *Handbook of Infant Perception* volume 1 *From Sensation to Perception* Eds P Salapatek, L Cohen (Orlando, FL: Academic Press)
Ullman S, 1989 "Aligning pictorial descriptions: An approach to object recognition" *Cognition* **32** 193-254

van Giffen K, Haith M M, 1984 "Infant visual response to gestalt geometric forms" *Infant Behavior and Development* **7** 335 – 346

Wertheimer M, 1923/1958 "Principles of perceptual organization", in *Readings in Perception* Eds S Beardslee, M Wertheimer (Princeton, NJ: Van Nostrand Reinhold 1958); translated from German by M Wertheimer (originally published in 1923)

Witkin A P, Tenenbaum J M, 1983 "On the role of structure in vision", in *Human and Machine Vision* Eds J Beck, B Hope, A Rosenfeld (New York: Academic Press) pp 481 – 543

Woodward A L, Markman E M, Fitzsimmons C M, 1991 "Children's rate of learning new words: Is the "naming explosion" a learning explosion?", paper presented at the biennial meetings of the Society for Research in Child Development, Seattle, WA (abstract)

Wynn K, 1992 "Addition and subtraction by human infants" *Nature (London)* **358** 749 – 750

Xu F, Carey S, 1992 "Infants' concept of numerical identity", paper presented at the Boston University Language Acquisition Conference, Boston, MA (abstract)

Yonas A, Granrud C E, 1984 "The development of sensitivity to kinetic, binocular, and pictorial depth information in human infants", in *Brain Mechanisms and Spatial Vision* Eds D Ingle, D Lee, M Jeannerod (Amsterdam: Martinus Nijhoff Press)

Yonas A, Granrud C E, 1985 "Reaching as a measure of infants' spatial perception", in *Measurement of Audition and Vision in the First Year of Life* Eds G Gottlieb, N Krasnegor (Norwood, NJ: Ablex)