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Perceptual Completion of Surfaces in Infancy

Nancy Termine, Timothy Hrynick, Roberta Kestenbaum,
Henry Gleitman, and Elizabeth S. Spelke
University of Pennsylvania

Two experiments provide evidence that 4-month-old infants perceive background surfaces as continuous behind occluding objects. Infants were shown a partly hidden background surface either for a brief period of familiarization (Experiment 1) or until they met a criterion of habituation (Experiment 2). The infants were then tested with nonoccluded surfaces that were either continuous or interrupted by a gap where the occluder had been. The infants in each study looked longer at the interrupted than at the continuous surface, relative to infants in baseline controls, which suggests that the partly hidden surface was perceived as continuous. Contrasting findings were obtained in a third experiment, in which infants were habituated to a partly hidden surface that stood in front of a background so that its edges were visible: Infants gave no evidence of perceiving the foreground surface as continuous behind the occluder. These experiments provide evidence that infants perceive a surface as continuous only if it serves as the background of a scene. The results are discussed in relation to figure–ground perception in pictures and surface layouts.

Humans live in a world of extended surfaces furnished with distinct and separable objects. In many settings, the objects are so numerous that the extended surfaces are largely hidden from view: Humans see little of the ground that supports them, for example, when they walk through a cluttered room. Adults perceive most extended surfaces as continuous behind objects despite this occlusion, as perception psychologists have long noted (e.g., Gibson, 1950; Koffka, 1935). The present research begins to investigate the origins of this phenomenon in infancy.

According to the Gestalt psychologists, perception of surfaces depends on a tendency to organize the visual field into regions of "figure" and "ground" (Koffka, 1935; Rubin, 1921/1958). When a perceiver confronts a pictorial arrangement of two regions differing in color and brightness, the regions will appear to be distinct and separated in depth, and the contour between them will appear to belong only to the region that is perceptually closer—the figure. Lacking this contour, the other region will appear to extend indefinitely behind the figure and to form a continuous ground. Factors influencing the selection of a region as figure include its shape and its arrangement in the picture: A region is more likely to be seen as the figure if it is regular in form and if it is surrounded by the other region (Rubin, 1921/1958). Figure–ground organization could explain, therefore, why perceivers see extended surfaces as continuous behind occluding objects. In most two-dimensional projections of a three-dimensional scene, the visible regions of extended surfaces are irregular in shape and surround the objects that partly hide them.

In Gestalt theory, figure–ground organization occurs as a consequence of force fields arising automatically in the central nervous system, and thus it is not dependent on learning. Certain empiricist theorists have also suggested that the capacity to separate figure from ground is innate and serves as a basis for perceptual learning (Hebb, 1949). On these views, even inexperienced infants should perceive background surfaces as continuous behind occluding objects.

Despite its popularity, there are reasons to question the Gestalt analysis. Experiments on form perception have tended to undermine the notion that perceivers have a single, general tendency to confer the simplest organization on visual scenes (see Hatfield & Epstein, 1985; Hochberg, 1973; Kubovy & Pomerantz, 1981; Rock, 1975). Neurophysiological experiments have also failed to support the physiological theory proposed to account for this tendency (e.g., Lashley, Chow, & Semmes, 1951; Sperry & Miner, 1955). Finally, studies of form and object perception fail to confirm Gestalt theory's developmental predictions. When presented with two-dimensional patterns, infants under 6 months have been shown to detect properties such as vertical symmetry (Bornstein, Ferdinandsen, & Gross, 1981), good continuation (van Giffen & Haith, 1983), and good form (Bomba & Siqueland, 1983; Strauss & Curtis, 1981), but infants do not use these properties to confer the most regular organization on such patterns (Bertenthal, Campos, & Haith, 1980; Bower, 1965; Salapatek, 1975). When presented with three-dimensional scenes, young infants have been shown to perceive objects by detecting surface arrangements (Hofsten & Spelke, 1985; Kestenbaum, Termine, & Spelke, in press; Prather & Spelke, 1982) and motions (Hofsten & Spelke, 1985; Kellman & Spelke, 1983; Kellman, Spelke, & Short, 1986), but they fail to perceive objects by analyzing surface colors and textures, edge alignment, or figural symmetry (Kellman & Spelke, 1983;

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Correspondence concerning this article should be addressed to Elizabeth S. Spelke, Department of Psychology, Cornell University, Uris Hall, Ithaca, New York 14853.

Kestenbaum et al., in press ; Prather & Spelke, 1982; Schmidt & Spelke, 1984; Schmidt, Spelke, & LaMorte, 1986; Schwartz, 1983).

These findings were obtained, in part, from research on infants' perception of partly occluded objects. In a series of experiments, 4-month-old infants were habituated to an object whose top and bottom were visible but whose center was hidden by a second object. After habituation, the occluding object was removed, and infants were presented, on alternating trials, with a complete object and with two object pieces separated by a gap where the occluder had been. The complete object was the object adults report seeing in the occlusion display: It was formed by connecting the visible ends of the occluded object so as to create the "best" gestalt. The object with the gap corresponded just to the visible surfaces of the occluded object: It is the display that infants would have seen during habituation if they perceived the world as a mosaic of colored patches, as some psychologists have proposed (e.g., Piaget, 1952; Titchener, 1909). Control experiments using this method have provided evidence that habituation to a partly occluded object generalizes to a display in which that object appears fully visible without the occluder and that infants look longer at a display consisting of a new object (see Kellman & Spelke, 1983; Spelke, 1985). If infants perceived the center-occluded objects as complete, therefore, they were expected to look longer at the interrupted display.

These experiments provided evidence that perception of a partly occluded object is unaffected by gestalt properties such as the homogeneity of the object in color and texture and the regularity of its shape. Infants perceive a partly hidden object as a connected unit if its visible surfaces undergo a common motion (Kellman, Gleitman, & Spelke, 1987; Kellman & Short, 1985; Kellman & Spelke, 1983; Kellman et al., 1986), but this perception is unaffected by the object's regularity of form and color (Kellman & Spelke, 1983). Moreover, infants have no determinate perception of a stationary, partly hidden object that is uniformly colored, smoothly contoured, and regular in form (Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Schmidt et al., 1986; Schwartz, 1983). Perception of partly occluded objects evidently does not depend on these configurational properties.

Such findings raise anew the question whether infants perceive background surfaces as continuous behind occluding objects. Background surfaces are usually stationary, and any motion they undergo tends to be perceived by infants as movement of the self (Butterworth & Hicks, 1977; Lee & Aronson, 1974). It is possible, therefore, that infants' perception of partly occluded background surfaces is no more determinate than their perception of partly occluded stationary objects. Background surfaces differ from objects, however, in a number of respects. Most notably, the background is by definition the most distant surface in a scene. Because young infants are sensitive to the relative distances of surfaces (see Banks & Salapatek, 1983, and Gibson & Spelke, 1983, for reviews), they might differentiate objects from backgrounds on this basis and perceive the latter as continuous.

In the present experiments we investigated whether 4-month-old infants perceive an extended vertical surface as continuous behind a narrow screen. In different experiments, infants were presented with a large surface, a small surface with no visible edges, and a small surface with visible edges. The first experiment used a new method—the "disocclusion method"—to assess infants' immediate impression of a partly hidden surface. The second and third experiments used the habituation method from previous research.

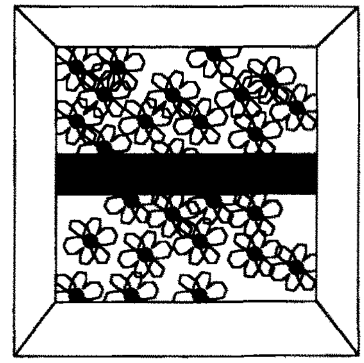

Figure 1. The occlusion display for Experiment 1.

Experiment 1

Infants were presented with a large, flat, vertical surface with regular patterning. Viewed through a stage, the surface had no visible edges, and thus it appeared to adults to extend indefinitely beyond the borders of the stage. The surface was partly occluded by a narrow horizontal screen that completely bisected its image in the visual field (Figure 1). In Experiment 1 we investigated whether infants perceived the surface as continuous behind this screen.

Perception of the continuity of the background surface was assessed by measuring infants' looking time at events in which the surface was disoccluded. The infants in an experimental condition were allowed to look at the partly occluded surface for 5 s, and then the occluder was removed to reveal either a continuous surface or a surface with a horizontal gap in the occluder's former position. This surface remained in view as long as an infant looked at it, and looking time was measured. Looking times were compared with those of infants in a baseline condition who viewed nonoccluded continuous and interrupted surfaces, following a similar procedure. If infants perceive background surfaces as continuous, then the interrupted surface should have appeared relatively novel to the infants in the experimental condition, and the event in which it was revealed should have provoked a reorganization of the scene. For both reasons, those infants should have looked longer, relative to baseline, when disocclusion revealed the interrupted surface.

Method

Subjects. Participants were 32 full-term infants from the Philadelphia area. The 16 boys and 16 girls ranged in age from 3 months, 25 days to 4 months, 25 days (M age = 4 months, 9 days). Sixteen additional infants were rejected from the sample because of technical problems (4) or fussiness (12).

Displays and apparatus. Each subject sat in an infant seat facing a 74 × 66 × 76-cm display stage with white side walls and a white floor. Standing 10 cm behind the open back of this stage was a flat, vertical surface covered with a maroon floral pattern. It extended behind the stage in all directions so that its edges were not visible. Two surfaces were displayed on different trials: a continuous surface and a surface bisected by a 6-cm horizontal gap just below the infant's eye level. The gap in the interrupted surface revealed a second surface covered with the same floral patterning, 30 cm further away. At the start of each trial, a gray, 10-cm-wide occluder extended across the stage, 7.5 cm in front of the background surface. This occluder, which fully hid the gap in the interrupted surface, could be drawn completely out of view through a slit in the right wall of the stage. From the infant's stationpoint (126 cm from the center of the background surface), the background surface subtended 33° × 30°, the occluder was 6° wide, and the gap in the interrupted surface was 3° wide. Three fluorescent lights mounted above the stage provided equal illumination for the occluder, the background surface, and the smaller surface behind the interrupted surface. A beige curtain that opened and closed mechanically covered the display between trials.

Design. Equal numbers of male and female infants were assigned to the experimental and baseline conditions. Infants were given two trials with each surface. The two surfaces appeared in alternation, with order counterbalanced across subjects in each condition.

Procedure. Each infant was placed in the seat and centered in front of the stage with the curtain closed. In the experimental condition, the curtain opened to reveal one of the surfaces with the occluder in place. After the infant looked at the display for 5 s cumulatively, the occluder was moved horizontally to reveal the center of the surface; this event lasted 2.5 s. The surface then remained in view until the infant looked at it for at least 1 s cumulatively and then looked away for 2 s continuously. Then the curtain was closed, the second background surface was placed behind the display, the occluder was repositioned, and the curtain was reopened to begin the next trial. The intertrial interval was 8 s.

The same procedure was followed in the baseline condition, except that no occluder was presented. The curtain was opened to reveal either the continuous or the interrupted surface. After the infant looked at that surface for 5 s, 2.5 s were allowed to pass, and then the surface remained visible until the infant looked at it for at least 1 s and then looked away for 2 s. Then the curtain was closed, the backgrounds were switched, and the curtain was reopened 8 s later to begin the next trial.

Looking time was monitored continuously by two experimenters who observed the infant through peepholes to the left and right of the display. The observers did not know which display was presented on a given trial; they recorded looking time by depressing buttons connected to a polygraph. Interobserver reliability—the proportion of time the two observers agreed that the infant was or was not looking at the display—averaged .86. A third assistant watched the polygraph and determined both when the occluder should be removed and when the trial should end. A fourth experimenter moved the occluder, controlled the curtain, and changed the displays.

Data analysis. Looking time was analyzed only during the last portion of each trial: after a surface had been disoccluded in the experimental condition and after an analogous amount of time had passed in the baseline condition.[1] These times were log-transformed to correct for the positive skew that is often found in an infant-control procedure (e.g., Gibson, Owsley, & Johnston, 1978), and they were analyzed by a 2 (condition) × 2 (order) × 2 (display) × 2 (trial pair) ANOVA, with the last two being within-subjects factors.

Results

The principal findings appear in Figure 2. Infants in the experimental condition looked longer at the interrupted surface than at the continuous surface, whereas infants in the baseline condition showed the reverse preference. The interaction of Condition × Display was significant, $F(1, 28) = 6.34$, $p < .02$. The analysis also revealed main effects of condition, $F(1, 28) = 6.61$, $p < .02$, and of trial pair, $F(1, 28) = 4.77$, $p < .05$. Looking times were longer, in general, in the experimental condition, and they were longer on the first pair of trials.[2]

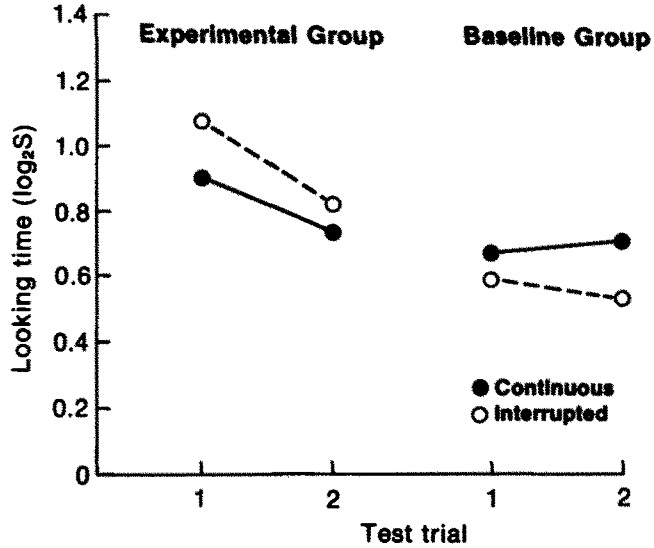

Figure 2. Log-transformed looking times in Experiment 1 by infants in the experimental condition, after disocclusion of the surface, and by infants in the baseline condition.

Discussion

After brief familiarization with a partly occluded surface, 4-month-old infants looked longer at a surface with a gap that at a continuous surface, relative to baseline. This looking pattern suggests that the infants in the experimental condition perceived the partly hidden background surface as continuous behind the occluder. Infants may distinguish background surfaces from object surfaces, perceiving only the former as continuous behind occluding objects.

These conclusions can be questioned, however, for two reasons. First, evidence that infants perceived the background surface as continuous rests on a comparison between the experimental and baseline groups, but those groups differed significantly in their overall looking times during the test. It is possible, therefore, that the differing preferences of the two

[1] Results are not changed substantively if looking time throughout the trial is analyzed for the baseline condition.

[2] An analysis of untransformed looking times revealed main effects of condition $F(1, 28) = 6.39$, $p < .02$, and of trial pair, $F(1, 28) = 7.52$, $p < .02$, but only a marginally significant Condition × Display interaction, $F(1, 28) = 2.95$, $p < .1$. Mean looking times in seconds (with standard deviations) for the interrupted and continuous surfaces were 13.7 (11.0) and 11.5 (13.1) for the experimental group and 5.1 (3.8) and 6.4 (4.3) for the baseline group.

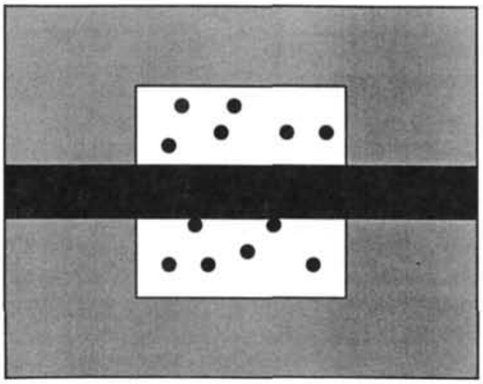

Figure 3. The occlusion display for Experiment 2. (The central, dotted surface appeared through an aperture in the surrounding white surface.)

groups were caused by their different levels of attentiveness: Infants may look longer at an interrupted display when attention is high and at a continuous display when attention is low. Research with partly occluded objects casts doubt on this possibility. Although variations in baseline procedures have produced considerable variation in infants' total looking times, they have not affected infants' preferences between a continuous and an interrupted object (cf. Kellman & Spelke, 1983; Kellman et al., 1986). It would be desirable, nevertheless, to compare the test display preferences of experimental and baseline groups whose overall looking times were equivalent.

A second problem concerns the comparison of Experiment 1 with previous research with partly occluded objects. This comparison is problematic, because Experiment 1 differed from its predecessors in several respects. One difference concerns the size of the present display. The background surface in this experiment was larger than any of the objects in previous studies, and it may have been more prominent for the infants. A second difference concerns the method used in the present experiment. The disocclusion method may provide a more sensitive test of perceptual completion than the habituation method, or it may tap perceptual functioning at a different level. Experiment 2 was undertaken to address these problems.

Experiment 2

The infants in the experimental condition of Experiment 2 were presented with a partly hidden surface behind an aperture in a larger surface so that none of its edges were visible (Figure 3). It was the most distant surface in view, from the infant's stationpoint, and it appeared to adults to form the background of the scene (see Experiment 4). Its visible areas were comparable in size to the objects used in previous research (e.g., Schmidt & Spelke, 1984) and were considerably smaller than the surface from Experiment 1. Perception of this surface was tested by means of the habituation method used in previous experiments with partly hidden objects (e.g, Kellman & Spelke, 1983; Schmidt & Spelke, 1984; Schwartz, 1983). After habituation to the partly occluded surface, looking times at continuous and interrupted surfaces were measured and were compared with the looking times exhibited by infants in a baseline condition. In hopes of obtaining a baseline comparison in which overall looking times were equivalent to those of infants in the experimental condition, we divided infants in the baseline condition into two groups. One group viewed the test surfaces after six trials of prior exposure to similar displays; the other group was presented with the test surfaces immediately. If infants perceive a background surface as continuous behind an occluder, the infants in the experimental condition should have looked longer at the interrupted surface than at the continuous surface, relative to baseline.

Method

Subjects. Participants were 32 full-term infants from the Philadelphia area. The 18 boys and 14 girls ranged in age from 3 months, 22 days to 4 months, 24 days (*M* age = 4 months, 9 days). Four additional subjects did not complete the experiment because of fussiness.

Displays and apparatus. The subjects were seated in an infant seat before the same curtained stage as in Experiment 1. Within this stage was a white, textured surface with a central, 30 cm × 30-cm (21°) aperture. A continuous or interrupted background surface stood 12 cm behind this aperture, 92 cm from the infant. It was painted yellow and textured with blue and red dots. Because the edges of the surface were not visible, it appeared to extend indefinitely behind the white screen. The continuous and interrupted surfaces were identical except that the latter was bisected by a 4-cm (3°) horizontal gap. A white textured surface was suspended 12 cm behind this gap.

During the experimental group's habituation trials, the white textured surface and one of the two background surfaces were presented behind a gray, 10-cm (8°) wide, horizontal occluder (Figure 3). The occluder stood 3.5 cm in front of the white surface and aperture, 76 cm from the infant. Because the occluder completely covered the gap in the interrupted surface, the continuous and the interrupted surfaces looked identical to adults during the habituation trials. During the test trials for both the experimental and the baseline groups, the two surface displays were presented without the occluder.

Design. Equal numbers of infants were assigned to the experimental and baseline conditions. The infants in the experimental condition were habituated to a partly occluded surface (the continuous surface for half the infants and the interrupted surface for the others) and then were given three alternating presentations of the nonoccluded continuous and interrupted surfaces, in counterbalanced order. The infants in the baseline condition were given the same counterbalanced test trials, as well as the six test trials for Experiment 3 (see below). Half the infants in the baseline condition were given the present test trials after the test trials of Experiment 3; the other infants received the present test first.

Procedure. A subject was placed in the infant seat and centered in front of the display with the curtain closed. In the experimental condition, each habituation trial began when the curtain opened to reveal the center-occluded display. The trial continued until the baby had looked at the display for at least 1 s cumulatively and then had looked away for 2 s continuously. The curtain closed at the end of the trial and reopened 3 s later to begin the next trial. Habituation trials were presented until 14 trials had been given or until a criterion of habituation was met, whichever came first. The criterion was a 50% decline in total looking time on 3 consecutive trials, relative to the infant's looking time on the first 3 trials for which looking time equaled or exceeded 12 s. The mean number of habituation trials was 10. After the last habituation trial, the curtain was closed, the occluder was removed, and the 6 test trials were presented according to the same procedure as the habituation trials. In the baseline condition, the experiment began with these 6 test trials.

Two experimenters, naive to the particular display shown on each test trial, recorded the infant's looking time during the course of the study by depressing buttons connected to a microprocessor. Interobserver reliability averaged .88. The microprocessor automatically stored the data, signaled the end of a trial, and calculated and signaled the criterion of habituation. A third experimenter changed the displays.

Dependent measures and data analysis. For purposes of analysis, looking times during the test trials were log-transformed to correct for positive skew. Preliminary analyses revealed that looking preferences in the experimental condition were unaffected by the particular background surface (continuous vs. interrupted) presented during habituation ($t < 1$), a finding indicating that infants were not affected by any extraneous differences between the two surfaces. This factor was not considered further. Looking patterns were analyzed by a 2 (condition) × 2 (test order) × 2 (test display) × 2 (trials pair) ANOVA, the last two factors being within subjects.

Results

Figure 4 presents the principal findings. Infants in the experimental condition looked longer at the interrupted surface than at the continuous surface, whereas infants in the baseline condition showed the reverse preference. The interaction of condition with test display was significant, $F(1, 28) = 4.03$, $p = .05$, but it was complicated by a triple interaction of condition, test display, and trial pair, $F(1, 56) = 4.12$, $p < .025$. Separate analysis of each pair of trials revealed that the experimental group showed a greater preference for the interrupted surface than did the baseline group on the first pair of trials, $F(1, 28) = 8.65$, $p < .01$, but not on the second or third trial pairs (both Fs < 1). There was also an interaction of condition with test order, $F(1, 28) = 8.80$, $p < .01$, indicating that looking times were higher for the experimental group infants who viewed the interrupted surface first and for the baseline group infants who viewed the continuous surface first. Overall looking times did not differ between the experimental and the baseline conditions.[3] To our surprise, looking times were no shorter for the baseline infants who were previously exposed to similar displays than for the baseline infants who were not (total looking during the test series averaged 41.1 s and 48.4 s, respectively). Preferences between the continuous and the interrupted surfaces did not differ for the two baseline groups ($t < 1$).

Discussion

In this experiment, habituation to the center-occluded surface was followed by longer looking at the interrupted surface, relative to baseline. Because the infants in the experimental and baseline conditions did not differ in overall levels of attentiveness, their differing preferences appear to be due to the experimental group's habituation experience. The experiment provides evidence that the infants in the experimental condition perceived the partly hidden background surface as continuous behind the occluder.

In Experiment 2 we used the same method as in previous research with partly occluded objects, and we presented infants with a surface that was no larger than the objects that have previously been studied. The experiment suggests, therefore, that infants differentiate between stationary objects and stationary backgrounds, perceiving only the latter as continuous.

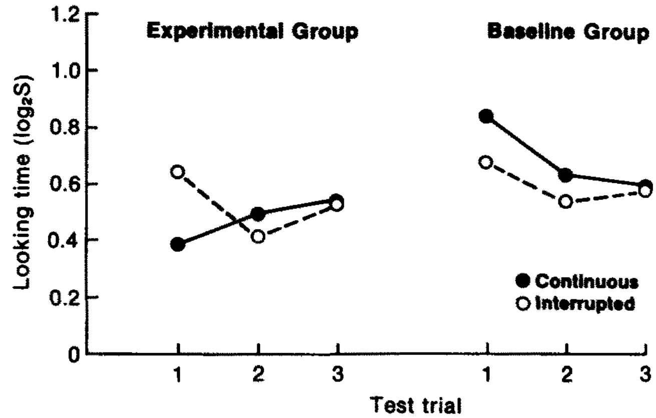

Figure 4. Log-transformed looking times in Experiment 2 by infants in the experimental condition, after habituation to a partly occluded surface, and by infants in the baseline condition.

On what basis do infants differentiate objects from background surfaces? According to the Gestalt psychologists, figure-ground differentiation depends on pictorial relations in a scene: A region is more likely to be perceived as the ground if its visible areas are irregular in form and if they surround the other regions in the display. In Experiment 2, however, the visible region of the background surface was regular in form—a square—and was itself surrounded by the white surface in front of it. It seems more likely, therefore, that infants differentiate objects from backgrounds by detecting information for three-dimensional properties of a scene, perceiving the most distant surface as a continuous ground. In Experiment 3 we investigated this possibility more directly by presenting infants with an occlusion display that was pictorially similar to the display of Experiment 2 but in which the depth relations among surfaces were reversed.

Experiment 3

Infants were shown a surface of the same color, texture, and dimensions as the visible areas of the background surface from Experiment 2. This surface appeared at the same distance from the infant as that background surface, and it was partly hidden behind the same horizontal occluder. The surface appeared, however, in the foreground: It was suspended in front of a white surface, its edges clearly in view. The different depth relations in the displays of Experiments 2 and 3 were clearly detectable by adults (see Experiment 4). The displays for the two experiments

[3] An analysis of untransformed looking times revealed significant interactions of Condition × Display, $F(1, 28) = 6.22$, $p < .01$, and of condition × Order, $F(1, 28) = 8.11$, $p < .01$. The Condition × Display × Trial Pair interaction was not significant. Mean looking times in seconds (with standard deviations) for the interrupted and continuous surfaces were 4.8 (3.0) and 4.1 (3.1) for the experimental group and 4.9 (2.7) and 8.4 (8.3) for the baseline group.

were pictorially so similar, however, that slide photographs of them proved to be indistinguishable.[4]

Perception of the continuity of the foreground surface was tested as in Experiment 2. If infants perceive partly occluded surfaces by responding to pictorial relations in a display, then the infants in Experiment 3 should have exhibited the same patterns of dishabituation as the infants in Experiment 2: Infants in the experimental condition should have looked longer at the interrupted surface, relative to infants in the baseline condition. If infants perceive partly occluded surfaces by detecting information for the depth relations in a display, perceiving only the most distant surface as continuous, then the infants in Experiment 3 should have exhibited the same patterns of dishabituation as do infants in studies with stationary objects: Infants in the experimental and the baseline conditions should have shown the same preference between the continuous and interrupted surfaces.

Method

The method was the same as that of Experiment 2, except as follows.

Subjects. The 32 participants (18 girls, 14 boys) ranged in age from 3 months, 21 days to 4 months, 21 days (*M* age = 4 months, 7 days). Two additional babies failed to complete the experiment because of fussiness.

Displays. Inside, the display stage was a flat, 30 × 30-cm continuous or interrupted surface. This surface had the same color and texture as the background surface in Experiment 2. It appeared at the same distance of 92 cm from the infant, 12 cm in front of a white textured background. The continuous and interrupted surfaces were identical except for the 4-cm horizontal gap across the interrupted surface, through which the white background could be seen. During the habituation trials, the continuous or interrupted surface was partly occluded, as in Experiment 2. A drawing of this display, taken from the infant's stationpoint, would look like Figure 3.

Design, procedure, and analysis. These were the same as in Experiment 2. The mean number of habituation trials was 11. Interobserver reliability averaged .86. Test trial looking preferences in the experimental condition were unaffected by the nature of the surface hidden behind the occluder (continuous vs. interrupted) ($t < 1$), and so this factor was ignored in the main analysis.

Results

Figure 5 presents the principal findings. Infants in both the experimental condition and the baseline condition appeared to look slightly longer at the interrupted display, though this tendency was not significant, $F(1, 30) = 1.16$, $p > .2$. The Condition × Test Display interaction also was not significant, $F(1, 28) = 0$ (Figure 6). The only significant factors in the analysis were main effects of order, $F(1, 28) = 5.33$, $p < .05$, and trial pair, $F(2, 56) = 4.34$, $p < .02$. Looking times were longer for the infants presented first with the interrupted surface, and looking times were longer for all infants on the first pair of test trials.[5]

Discussion

Experiment 3 provided no evidence that infants perceived the foreground surface as continuous behind the occluder. In contrast to Experiment 2, habituation to the center-occluded display was not followed by differential looking at the continuous and interrupted surfaces, relative to baseline. This finding accords with those of studies of perception of partly occluded stationary objects (e.g., Kellman & Spelke, 1983; Schmidt & Spelke, 1984). It suggests that infants perceive the continuity of a partly hidden surface only if they detect information that the surface is the most distant part of a scene, with no occluding edges in view.

Inspection of Figures 4 and 5 suggests that the most striking difference between Experiments 2 and 3 concerns the baseline groups: Whereas infants exhibited a baseline preference for the continuous background, they exhibited no such preference for the continuous object. This baseline difference appears to be genuine, for it was found with displays that are otherwise so similar that adults fail to discriminate them in photographs (footnote 4). What is more, this difference is corroborated by independent experiments. The preference for a continuous background surface was obtained both in Experiment 1 and in Experiment 2, studies using different methods and different displays, whereas the absence of a preference for a continuous object has been documented in a large number of studies of perception of partly hidden objects (e.g., Kellman & Spelke, 1983; Kellman et al., 1986, 1987).

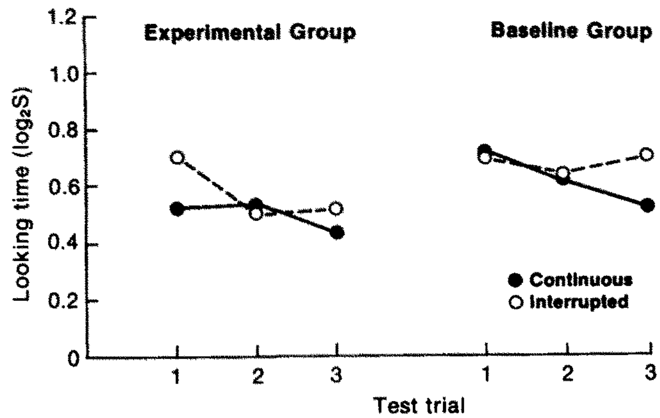

Figure 5. Log-transformed looking times in Experiment 3 by infants in the experimental condition, after habituation to a partly occluded surface, and by infants in the baseline condition.

[4] Six adults were shown slide photographs, taken from the infant's stationpoint, of the four occlusion displays from Experiments 2 and 3. When asked to describe each display, every subject reported that the yellow surface appeared to be in front of the surrounding white surface in all four displays. This report accords with the Gestalt analysis of figure–ground organization. When asked whether the four slides depicted the same or different displays, all the subjects reported that they depicted the same display. Even the experimenters could not distinguish the displays from these photographs.

[5] An analysis of untransformed looking times revealed effects of order, $F(1, 28) = 3.92$, $p < .06$, and trial pair, $F(1, 28) = 4.12$, $p < .05$, and no other effects or interactions. Mean looking times in seconds (with standard deviations) for the interrupted and continuous surfaces were 5.5 (4.2) and 4.2 (1.9) for the experimental group and 7.6 (10.1) and 8.0 (9.1) for the baseline group.

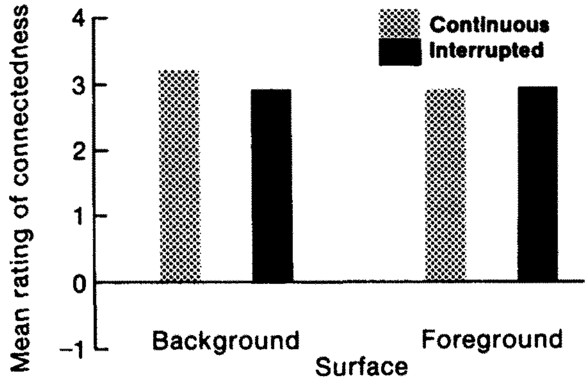

Figure 6. Mean ratings by adults of the connectedness over occlusion of each background and foreground surface.

We have no explanation for this baseline effect. Note, however, that the effect underscores the need for baseline comparisons when the habituation method is used to investigate perception in infancy. In Experiment 3, habituation to a partly occluded object evidently had no effect on infants' preferential looking at nonoccluded complete and broken objects. This finding, corroborated by the findings of more than 10 other experiments (see Spelke, 1985, for a review), provides evidence that infants do not perceive partly hidden stationary objects as continuous. In Experiment 2, in contrast, habituation to a partly occluded background surface led infants to overcome their general preference for a continuous surface and to look longer at an interrupted surface. This finding, corroborated by Experiment 1, provides evidence that infants perceive stationary background surfaces as continuous behind occluding objects.

It is curious that infants' perception of partly occluded surfaces should depend on the relative depth relations in a scene, for this would not appear to be the case for adults. Although adults distinguish foreground from background surfaces, they tend to perceive both types of surfaces as continuous behind occluding objects (Michotte, Thinès, & Crabbé, 1964; Kellman & Spelke, 1983; Schmidt, 1985). It is possible, nevertheless, that depth relations exert some subtle influence on adults' perception of surface continuity. Such an influence might be manifest if depth relations in a display were varied while other properties of the display were held constant. In Experiment 4, we investigated adults' perception of the background and foreground surfaces used in the habituation experiments with infants.

Experiment 4

College students were shown the habituation displays of Experiments 2 and 3. They were asked whether the visible ends of each surface appeared to continue behind the occluder, and they were asked to rate the strength of their impression of continuity or interruption. If depth relations influence perceptual completion for adults as they do for infants, then the adults' impression of surface continuity should have been stronger for the background surface than for the foreground surface.

Method

The method followed that of Kellman and Spelke's (1983) studies of adults' perception of partly occluded objects (see Kellman & Spelke, 1983, for a more detailed description). Participants were 8 undergraduate students with no course or laboratory experience in perception or infant development. Each subject viewed the four displays presented to infants for habituation: the partly occluded continuous and interrupted background surfaces, and the partly occluded continuous and interrupted foreground surfaces. (Note that the continuous and interrupted surfaces were designed to appear identical when viewed with the occluder.) The adults viewed the surfaces in the same display box and from the same stationpoint as the infants. Displays were presented for 3 s each, in a Latin-square order.

After viewing a display, subjects were asked whether the yellow surface appeared to be continuous or interrupted behind the occluder. They were told to base the responses on their immediate impression of the surface, rating the strength of that impression on a scale from +4 (*strong impression of continuity*) to −4 (*strong impression of discontinuity*). A demonstration and pretest with displays unrelated to the present ones were given to ensure that subjects understood the instructions (see Kellman & Spelke, 1983). After the experiment, the subjects were asked to describe each display. Ratings for each display were tested against the neutral point of 0 by z scores, and they were tested against each other by a one-way analysis of variance.

Results and Discussion

Mean ratings for the four displays are given in Figure 6. Each rating was significantly greater than 0 (all $zs > 2.23$, $p < .025$). The ratings did not differ from one display to another, $F(3, 28) = 0.3$, *ns*. In their subsequent descriptions of the displays, all the subjects mentioned the depth relations and differentiated correctly between the background and the foreground surfaces. They described every surface as continuous behind the occluder. There were no differences between each subject's description of the continuous versus interrupted surfaces.[6]

These findings provide evidence that adults perceive foreground surfaces as well as background surfaces as continuous behind occluding objects. Although the adult subjects detected and described correctly the depth relations in the displays, their perception of a surface's continuity was not affected by those depth relations. Adults appear to contrast with infants in this respect, although subjects at the two ages have not been compared directly by means of the same methods. Infants presented with the same background and foreground surfaces appear to perceive only the former as continuous behind an occluder.

General Discussion

The first two experiments in this series provide evidence for an early capacity to perceive background surfaces as continuous behind the objects that partly hide them. After viewing a partly

[6] The present findings provide a check on the displays shown to infants. They indicate that the continuous and interrupted surfaces, when occluded, did not differ in ways that influenced adults' judgments or descriptions. They also indicate that the three-dimensional displays were discriminably different to adults, although two-dimensional pictures of the displays were not (see footnote 4).

occluded background surface, 4-month-old infants looked less at a continuous surface than at a surface with a gap where the occluder had been. This looking pattern suggests that the partly hidden surface was seen as more similar to the continuous surface than to the surface that matched just its visible areas. The experiments, like studies of perception of partly hidden moving objects (Kellman & Spelke, 1983; Kellman, et al., 1986, 1987) provide evidence that young infants do not perceive the visual world as a mosaic of light-reflecting fragments but as a layout that continues in places where it is hidden.

The tendency to perceive the continuity of partly hidden background surfaces would appear to develop without benefit of extensive motor experience. At 4 months of age, an infant can neither reach for and remove an object nor locomote around it in order to bring its background into view. Although young infants can move their heads, thereby revealing small regions of a background surface that were hidden (see below), such movements will rarely reveal the occluded parts of the surface completely. Thus, perception of the continuity of background surfaces may depend on mechanisms that form part of humans' initial endowment, just as Hebb (1949) and others have suggested.

Although the infants in Experiments 1 and 2 perceived the continuity of a partly hidden background surface, those in Experiment 3 did not appear to perceive the continuity of an otherwise identical surface that stood in the foreground, even though that surface served in turn as a background for the occluding object. The displays of Experiments 2 and 3 were perceived differently, although static projections of them were not distinguishable by adults (see footnote 4). This finding casts doubt on the Gestalt thesis that perception of a continuous ground depends primarily on pictorial properties of the visual field such as the forms, colors, and encirclement relations among its regions. Infants' perception of a continuous ground appears to depend only on the three-dimensional arrangement of the surfaces in a scene.

Why might infants distinguish background from foreground surfaces, perceiving only backgrounds as continuous? It is possible that infants are attuned to information for occluding edges, for discontinuities in depth where one surface partly hides another. Patterns of accretion and deletion of visual texture provide such information (Gibson, 1979; Gibson, Kaplan, Reynolds, & Wheeler, 1969): When a moving observer views an unchanging scene, texture on the further of two overlapping surfaces is progressively revealed and concealed at the edge of the nearer surface, whereas texture on the nearer surface remains continuously in view. If infants view a partly hidden surface with occluding edges (as was the case in Experiment 3), they may be uncommitted as to whether further edges lie behind its occluder. If infants view a partly hidden surface with no such edges, however, they may perceive it as indefinitely extended, with no further edges in places where it is hidden.

This possibility is consistent with existing research. Young infants have been shown to be sensitive to accretion–deletion patterns (Kauffman-Hayoz, Kauffman, & Stucki, 1986) and to use such patterns as information for the depth relations among surfaces (Carroll & Gibson, 1981; Hofsten, personal communication, 1983; Yonas & Granrud, 1985). The present experiments did not manipulate sources of information for relative distance, however, and thus it is possible that infants distinguished the foreground and background surfaces by detecting a different kind of depth information.[7]

If the present findings have been interpreted correctly, it follows that infants should fail to perceive backgrounds as continuous in pictorial displays. Contrary to the expectations both of Hebb (1949) and of the Gestalt psychologists, infants should not organize a two-dimensional pattern into figure and ground even if they are presented with the simple configurations yielding the most powerful figure–ground effects for adults. This prediction remains to be investigated.

[7] Convergence, accommodation, and binocular disparity are unlikely to have influenced infants' perception at these distances. Pictorial cues may be ruled out, both because of the differing findings of Experiments 2 and 3, which used pictorially indistinguishable displays, and because infants of this age do not appear to be sensitive to pictorial depth information (Yonas & Granrud, 1985). Although optical flow has been little studied with infants, it is a plausible source of depth information in infancy (see Banks, 1986). Note, however, that flow patterns were limited to those which an infant could produce by moving the head and torso in a seated position.

References

Banks, M. S. (1986, April). *How can the developing visual system maintain veridical depth perception?* International Conference on Infant Studies, Los Angeles.

Banks, M. S., & Salapatek, P. (1983). Infant visual perception. In M. M. Haith & J. Campos (Eds.), *Handbook of child psychology: Vol. 2* (pp. 435–572). *Infancy and biological development.* New York: Wiley.

Bertenthal, B. I., Campos, J. J., & Haith, M. M. (1980) Development of visual organization: The perception of subjective contours. *Child Development, 51,* 1072–1080.

Bomba, P., & Siqueland, T. (1983). The nature and structure of infant form categories. *Journal of Experimental Child Psychology, 35,* 294–328.

Bornstein, M., Ferdinandsen, K., & Gross, C. G. (1981). Perception of symmetry in infancy. *Developmental Psychology, 17,* 82–86.

Bower, T. G. R. (1965). The determinants of perceptual unity in infancy. *Psychonomic Science, 3,* 323–324.

Butterworth, G., & Hicks, L. (1977). Visual proprioception and postural stability in infancy: A developmental study. *Perception, 6,* 255–262.

Carroll, J. J., & Gibson, E. J. (1981, April). *Differentiation of an aperture from an obstacle under conditions of motion by three-month-old infants.* Paper presented at the meeting of the Society for Research in Child Development, Boston.

Gibson, E. J., Owsley, C. J., & Johnston, J. (1978). Perception of invariants by five-month-old infants: Differentiation of two types of motion. *Development Psychology, 14,* 407–415.

Gibson, E. J., & Spelke, E. S. (1983). The development of perception. In J. H. Flavell & E. Markman (Eds.), *Handbook of child psychology: Vol. 3* (pp. 1–76). *Cognitive development.* New York: Wiley.

Gibson, J. J. (1950). *The perception of the visual world.* Boston: Houghton-Mifflin.

Gibson, J. J. (1979). *The ecological approach to visual perception.* Boston: Houghton-Mifflin.

Gibson, J. J., Kaplan, G. A., Reynolds, H. N., & Wheeler, K. (1969).

The change from visible to invisible: A study of optical transitions. *Perception & Psychophysics, 5,* 113–116.
Giffen, K. van, & Haith, M. M. (1984). Infant visual response to gestalt geometric forms. *Infant Behavior and Development, 7,* 335–346.
Hatfield, G., & Epstein, W. (1985). The status of the minimum principle in the theoretical analysis of visual perception. *Psychological Bulletin, 97,* 155–186.
Hebb, D. O. (1949). *The organization of behavior.* New York: Wiley.
Hochberg, J. (1973). Organization and the gestalt tradition. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception* (Vol. 1, pp. 180–211). New York: Academic Press.
Hofsten, C. von, & Spelke, E. S. (1985). Object perception and object-directed reaching in infancy. *Journal of Experimental Psychology: General, 114,* 198–212.
Kaufmann-Hayoz, R., Kaufmann, F., & Stucki, M. (1986). Kinetic contours in infants' visual perception. *Child Development, 57,* 292–299.
Kellman, P. J., Gleitman, H., & Spelke, E. S. (1987). Object and observer motion in the perception of objects by infants. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 586–593.
Kellman, P. J., & Short, K. R. (1985, June). *Infant perception of partly occluded objects: The problem of rotation.* Paper presented at the Third International Conference on Event Perception and Action, Uppsala, Sweden.
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. (1986). Infant perception of object unity from translatory motion in depth and vertical translation. *Child Development, 57,* 72–86.
Kestenbaum, R., Termine, N., & Spelke, E. S. (in press). Perception of objects and object boundaries by three-month-old infants. *British Journal of Developmental Psychology.*
Koffka, K. (1935). *Principles of gestalt psychology.* New York: Harcourt, Brace & World.
Kubovy, M., & Pomerantz, J. R. (1981). *Perceptual organization.* Hillsdale, NJ: Erlbaum.
Lashley, K. S., Chow, L., & Semmes, J. (1951). An examination of the electrical field theory of cerebral integration. *Psychological Review, 58,* 123–136.
Lee, D. N., & Aronson, E. (1974). Visual proprioceptive control of standing in human infants. *Perception & Psychophysics, 15,* 529–532.
Michotte, A., Thinès, G., & Crabbé, G. (1964). Les compléments amodaux des structures perceptives [Amodal completion of perceptual structures]. *Studia Psychologica.* Louvain: Publications Universitaires de Louvain.
Piaget, J. (1952). *The origins of intelligence in children.* New York: International Universities Press.
Prather, P., & Spelke, E. S. (1982, April). *Three-month-old infants' perception of adjacent and partly occluded objects.* Paper presented at the International Conference on Infant Studies, Austin, TX.
Rock, I. (1975). *An introduction to perception.* New York: Macmillan.
Rubin, E. (1958). Figure and ground. In D. C. Beardsley & M. Wertheimer (Eds.), *Readings in perception.* Princeton, NJ: D. Van Nostrand Company. (Original work published in German, 1921)
Salapatek, P. (1975). Pattern perception in early infancy. In L. B. Cohen & P. Salapatek (Eds.), *Infant perception: Vol. 1.* New York: Academic Press.
Schmidt, H. (1985). *The development of gestalt perception.* Unpublished doctoral dissertation, University of Pennsylvania.
Schmidt, H., & Spelke, E. S. (1984, April). *Gestalt relations and object perception in infancy.* Paper presented at the International Conference on Infant Studies, New York.
Schmidt, H., Spelke, E. S., & LaMorte, V. (1986, April). *The development of gestalt perception in infancy.* Paper presented at the meeting of the International Conference on Infant Studies, Los Angeles, CA.
Schwartz, K. (1983, April). *Perceptual knowledge of the human face in infancy.* Paper presented at the meeting of the Society for Research in Child Development, Detroit.
Sperry, R. W., & Miner, N. (1955). Pattern perception following insertion of mica plates into visual cortex. *Journal of Comparative and Physiological Psychology, 48,* 463–469.
Spelke, E. S. (1985). Preferential looking methods as tools for the study of cognition in infancy. In G. Gottlieb & N. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life* (pp. 323–364). Hillsdale, NJ: Erlbaum.
Strauss, M. S., & Curtis, L. E. (1981, April). *Infant perceptoin of patterns differing in goodness of form.* Paper presented at the meeting of the Society for Research in Child Development, Boston.
Titchener, E. B. (1909). *A textbook of psychology.* New York: Macmillan.
Yonas, J., & Granrud, C. (1985). Development of visual space perception in young infants. In J. H. Mehler & R. Fox, *Neonate cognition* (pp. 45–67). Hillsdale, NJ: Erlbaum.

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