Journal of Experimental Child Psychology **81,** 358–374 (2002)
doi:10.1006/jecp.2002.2657, available online at http://www.idealibrary.com on IDEAL®

Young Infants' Perception of Unity and Form in Occlusion Displays

Scott P. Johnson

Cornell University

J. Gavin Bremner

Lancaster University

Alan M. Slater

Exeter University

and

Uschi C. Mason and Kirsty Foster

Lancaster University

Young infants have been reported to perceive the unity of a center-occluded object when the visible ends of the object are aligned and undergo common motion but not when the edges of the object are misaligned (Johnson & Aslin, 1996). Using a recognition-based paradigm, the authors investigated the possibility that past research failed to provide sufficiently sensitive assessments of infants' perception of the unity of misaligned edges in partial occlusion displays. Positive evidence was obtained in 4-month-olds for veridical perception of the motion and location of a hidden region but not its orientation, whereas 7-month-olds, in contrast to the younger infants, appeared to respond to the orientation of the hidden region. Overall, the results suggest that habituation designs tapping recognition processes may be particularly efficacious in revealing infants' perceptual organization. In addition, the findings provide corroborative evidence for the importance of both motion and orientation in young infants' object segregation and for the difficulty in achieving percepts of the global form of a partly occluded object. © 2002 Elsevier Science (USA)

Key Words: object perception; object unity; infant visual perception; habituation.

This research was supported by Economic and Social Research Council (ESRC) Grant R000237093 and National Science Foundation Grants BCS 991079 and BCS 0094814. We gratefully acknowledge the efforts of the infants and parents who participated in the studies, and we thank the anonymous reviewers for their helpful comments on an earlier draft.

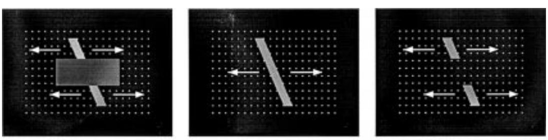
Address correspondence and reprint requests to Scott P. Johnson, Department of Psychology, Uris Hall, Cornell University, Ithaca, NY 14853. Fax: (607) 255-8433. E-mail: sj75@cornell.edu.

0022-0965/02 $35.00
© 2002 Elsevier Science (USA)
All rights reserved.

The visual environment that surrounds us is composed of image fragments that are reflected from object surfaces. Many objects are only partly visible because portions of their surfaces are occluded by other nearer objects. Nevertheless, our experience of the visual array consists not of isolated image fragments but rather of objects whose surfaces extend beyond what is directly visible. Veridical perception of the visual environment, therefore, relies on the ability both to segment visible surfaces (i.e., ascertain the depth plane within which each surface resides with respect to the observer) and to join those edges that define the same objects if the edges are separated by a gap induced by occlusion. These processes underlie perception of the unity and coherence of partly occluded objects, or *unit formation* (Kellman & Shipley, 1991; Nakayama, He, & Shimojo, 1995).

Investigations of the ontogenetic origins of unit formation are of vital importance for an understanding of how we perceive and understand the world, and they have attracted considerable attention in recent research. Infants' perception of object unity has been documented in those as young as 2 to 4 months of age with a habituation paradigm (e.g., Johnson & Aslin, 1995, 1996; Kellman & Spelke, 1983). Infants are shown a display repeatedly until looking decreases to a predetermined criterion, and then they view two test displays that are designed to match the habituation display in different ways. For example, one test display might match only the visible portions of the habituation display, whereas the other might match both visible and inferred portions, as adults would report (see Fig. 1). Young infants typically prefer posthabituation stimuli that are novel, relative to the habituation stimulus, over stimuli that are more familiar (Bornstein, 1985). Therefore, if infants look longer at one test display than at the other, this suggests that the preferred display differs more from what infants perceived during habituation. By comparing looking patterns across different displays, these perceived similarities and dissimilarities are used by researchers to determine how infants perceive object unity (for reviews, see Johnson, 1997, 2000).

Research on infants' unit formation has focused on two related issues: infants' detection and use of available visual information (which is manipulated by the experimenter) and the changes that occur with development in how infants use



A B C

FIG. 1. Displays employed in past research to investigate young infants' perception of partly occluded objects (adapted from Johnson & Aslin, 1996). (A) A partly occluded rod, with aligned edges, moves relative to a stationary occluder. (B) A complete rod. (C) A broken rod. After habituation to the partly occluded rod display, infants showed a preference for the broken rod relative to the complete rod, indicating perception of the rod's unity during habituation. A control group preferred neither test display.

this information and link visible edges across a gap. Earlier in the last century, the Gestalt psychologists described a range of visual information sources used to ascribe coherence to visible surface fragments (Koffka, 1935). For example, to perceive the unity of the visible rod parts in the occlusion display in Fig. 1A, an observer may note the common motion and good continuation characteristic of these rod segments and that, if unified, the rod parts would constitute good form. Motion and orientation cues are reliable indicators of object boundaries, unity, and form under conditions of partial occlusion, and explorations of their use by infants have provided key insights into the achievement of unit formation during ontogeny. Kellman and Spelke (1983; see also Kellman, Spelke, & Short, 1986), for example, reported that 4-month-old infants perceived the unity of two aligned rod parts undergoing common motion above and below a stationary occluder, a result that generalized to surfaces that were highly dissimilar and whose outer edges were not aligned.

The role of orientation cues in young infants' unit formation was explored further with displays in which good continuation was violated but common motion was maintained. Johnson and Aslin (1996) reported that 4-month-olds provided no evidence of unit formation when viewing two-dimensional (2D) occlusion displays containing rod parts whose edges were "relatable" (i.e., the edges were arranged such that they would intersect if extrapolated behind the occluder) but misaligned (see Fig. 2). Instead, the infants responded as if unity in this display was indeterminate, as reflected in a lack of posthabituation preference for either a broken or a complete object. (Adults responded verbally to the misaligned rod display also as indefinite with respect to connectedness [Johnson & Aslin, 1996; Jusczyk, Johnson, Spelke, & Kennedy, 1999].) Johnson and Aslin (1996) and Smith, Johnson, and Spelke (in press), in addition, found that 4-month-olds perceived rod parts as *disjoint* objects when the edges were nonrelatable (i.e., the edges would not intersect if extended behind the occluder), as reflected in a posthabituation preference for a complete object. These effects of edge misalignment were obtained despite the common motion of the surfaces.

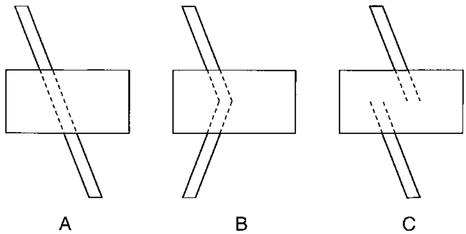


FIG. 2. (A) The edges of the rod parts are aligned above and below the occluder. They are relatable as well because they would meet to compose a smooth, monotonic contour behind the box. (B) The edges of the rod parts are relatable but not aligned. (C) The edges of the rod parts are neither aligned nor relatable.

These findings seem to indicate that both common motion and edge alignment are necessary for unit formation in 4-month-old infants but that neither is sufficient on its own. This conclusion may be too simplistic for several reasons. First, it is notable that all conditions employed by Johnson and Aslin (1996) used 2D, computer-generated displays, precluding the use of three-dimensional (3D) information to resolve depth differences among the rod, box, and background surfaces (information such as binocular disparity, motion parallax, accommodation, and convergence). It is possible that the addition of 3D information may bring infants' percepts closer to unity because connectedness might be more likely inferred if the observer perceives the rod parts as occupying a farther depth plane than the occluder. An experiment reported by Smith et al. (in press) is consistent with this possibility. When 4-month-olds were habituated to a 3D version of a misaligned rod stimulus and subsequently viewed broken and complete rod test displays, they showed no reliable preference. By contrast, infants who viewed 2D versions of these displays exhibited a posthabituation preference for a complete object, implying that infants' percepts were brought away from disjoint objects (in the 2D stimulus) and toward connectedness with the addition of 3D information. Second, two recent experiments indicate that young infants can achieve unit formation in the absence of edge alignment even in 2D displays, provided that common motion is available in tandem with good form (Johnson, Bremner, Slater, & Mason, 2000; Johnson, Cohen, Marks, & Johnson, 2001). As seen in Fig. 3, several kinds of good form appear to contribute to unity percepts. Finally, young infants appear to be largely insensitive to alignment as information for perceptual completion in static displays depicting partly occluded objects (Jusczyk et al., 1999; Kellman & Spelke, 1983) and illusory contours (Bertenthal, Campos, & Haith, 1980; but see Ghim, 1990). However, infants as young as 2 months of age perceive surface shape from motion information in random dot displays in the absence of visible edges (i.e., kinetic illusory contours) (Johnson & Mason, 2002; cf. Arterberry & Yonas, 2000). Taken together, therefore, the bulk of extant evidence supports the thesis that motion is the key to early perceptual organization.

The current studies sought to extend our knowledge in this area in two ways. First, we explored more subtle kinds of perceptual completion than have been

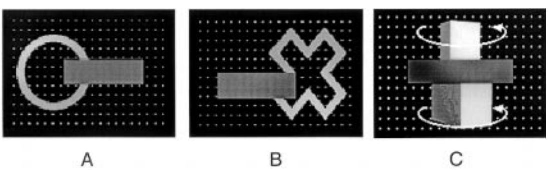


FIG. 3. Displays used to document the importance of common motion, in combination with good form, to specify unity to young infants. The 4-month-olds provided evidence of unity perception in all three displays, despite the fact that there was no information from edge alignment across the gap. (Panels A and B adapted from Johnson, Bremner, Slater, & Mason, 2000. Panel C adapted from Johnson, Cohen, Marks, & Johnson, 2001.)

tested to date. Visual cues such as common motion may induce a perceptual bias favoring the unity of the rod segments, but this bias might not always be captured in the "traditional" habituation design established by Kellman and Spelke (1983) to test perception of object unity (i.e., posthabituation presentation of broken and complete object displays). Under some circumstances, a weak bias may arise in favor of unity but might not encompass a clear expectation of the appearance of the hidden region. To investigate this possibility, we habituated infants to rod-and-box displays in which percepts of unity would be expected to be indeterminate if tested with the usual broken and complete stimuli: displays in which misaligned rod segments underwent common motion above and below an occluding box (as reported by Johnson & Aslin, 1996, and Johnson et al., 2000). A second advance introduced by the current research is that we examined changes with age in these more subtle unity percepts. We began by testing 4-month-olds because the majority of evidence in past research on infants' perception of object unity has used this age group, and much is known about how 4-month-olds use motion and other information to perceive unity. Our first three experiments are grounded in these findings. We also tested an older age group to follow up on questions that arose from the apparent failure of 4-month-olds to perceive unity in one of our conditions. Our hypotheses, then, were that young infants might perceive some aspects of unity in these displays, due to the strong influence of common motion in organizing and inducing such percepts, and that these aspects might be revealed by a more discriminating test than has been employed to date. In addition, we expected that more difficult aspects of unity might be accomplished only by older infants.

To test these hypotheses, we employed a paradigm that tapped infants' recognition of the rod parts' unity and the appearance of the hidden region. After habituation to a rod-and-box display with misaligned rod parts undergoing common motion, infants viewed test displays in which the hidden intersection of the rod parts was revealed (Fig. 4). One of the test stimuli preserved the previously hidden rod parts' intersection in displays that we termed *motion/location consistent* (MLC), *location consistent* (LC), and *orientation consistent* (OC). (Note that the MLC, LC, and OC displays are identical.) The second test stimulus violated one or more of these dimensions in displays that we termed *motion/location inconsistent* (MLI), *location inconsistent* (LI), and *orientation inconsistent* (OI).

The aim is to present departures from expectations of unity that are successively more subtle: (a) departure from both common motion and gross alignment (the *motion/location consistency* group), (b) departure from gross alignment alone (the *location consistency* group), and (c) departure from good form (the *orientation consistency* group). Our prediction is that departure from both common motion and alignment should be most easily detected and responded to as novel relative to the habituation display because of the powerful organizing effect of motion in perception of object unity. In addition, the MLI display violates an expectation of the location of the rod parts' intersection. Departure from gross alignment constitutes a crude misalignment of elements and may also be

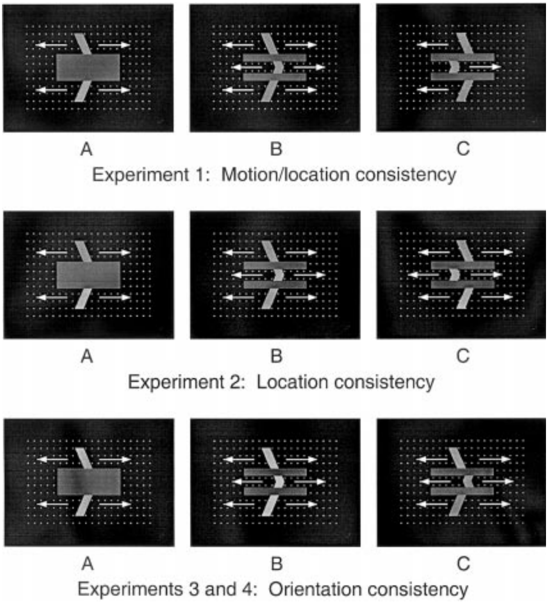


FIG. 4. Displays employed in the current experiments. (A) Rod parts are misaligned across the occluder, but relatable, conditions under which young infants have been found to be agnostic with respect to unity (adapted from Johnson & Aslin, 1996). (B) Consistent test displays. (C) Inconsistent test displays. The top panel shows displays used in Experiment 1, the center panel shows displays used in Experiment 2, and the bottom panel shows displays used in Experiments 3 and 4.

detected given infants' sensitivity to edge orientation in determinations of unity. Performance in the location condition, however, may be attenuated relative to the motion/location condition because common motion of surfaces in both test displays is preserved and might contribute to percepts of unity even in the LI display. Departure from good form is the most subtle; there are parts of the center portions of both test displays that are aligned with the outer rod parts, and it is only when the center is integrated with the peripheral parts as a unitary form that this figure looks "wrong" relative to a "good" figure. This analysis of orientation consistency, therefore, provides the most stringent test of veridical form perception in these displays.

Design

Each aspect of unity perception (motion/location, location, and orientation) was tested in an independent experiment with separate groups of 16 4-month-old infants. A fourth experiment tested a group of 7-month-olds in the orientation condition. Infants in the experimental conditions were first habituated to the rod-and-box stimulus depicted in Fig. 4, to be followed by the consistent display alternating with one of the three inconsistent displays during test. In four baseline conditions, separate groups of infants were presented the test stimuli with no prior habituation experience to investigate whether there might be an inherent preference for any of these displays. Unity percepts are revealed as a reliable preference by infants in the experimental conditions for the inconsistent display relative to the consistent display. No reliable preferences are expected on the part of infants in the baseline conditions.

EXPERIMENT 1: MOTION/LOCATION CONSISTENCY

The first experiment explored 4-month-olds' perception of object unity with the motion/location consistent and motion/location inconsistent displays. Recall that the MLI display violates both the motion and location of the hidden intersection (see Fig. 4), and this violation should be readily detected.

Method

Participants. The final sample consisted of 32 full-term infants (13 females and 19 males, mean age = 128.1 days, *SD* = 7.8). One additional infant was observed but not included in the analyses due to excessive fussiness. The infants were recruited by hospital visits and follow-up telephone calls. The majority were from Caucasian, middle-class families. Parents were paid a nominal sum for their participation.

Apparatus and stimuli. An Amiga 3000 computer and a 76-cm color monitor were used to present the stimuli and collect looking time data. Two observers, blind to the stimulus on the screen at all times, viewed the infant through peepholes cut into black panels on either side of the monitor. The computer presented displays, recorded looking time judgments, calculated the habituation criterion for each infant, and changed displays after the criterion was met. The observers' judgments were input via buttons connected to the computer's mouse port.

Each habituation display consisted of a 24.6 × 10.5 cm (14.0 × 6.0° visual angle) blue box, oriented horizontally. Two 9.0 × 3.8 cm (5.2 × 2.2°) green rod segments, oriented 27° clockwise (above the box) or counterclockwise (below the box), underwent lateral translation at a rate of 5.6 cm/s (3.2°/s). Objects were presented against a black background with a 12 × 20 grid of white dots measuring 48.8 × 33.0 cm (27.4 × 18.7°) serving as texture elements. In the test displays, a portion of the box was removed, 4.5 cm (2.6°) in height, such that the central part of the rod was visible as it translated. In the MLC test display, the central rod part was placed such that it was aligned with the top and bottom rod parts. In the MLI test display, the central rod part moved out-of-phase with the top and bottom rod parts. The intersection of the rod parts in the test displays all moved in the same pattern and at the same rate as the rod parts above and below the box (except the out-of-phase motion in the MLI display) and were presented against the same textured background.

Procedure. Each infant was seated 100 cm from the display and tested in a darkened room. Infants were assigned randomly to either the experimental or the baseline (no prior habituation) condition and to one of the two test display orders (consistent or inconsistent display first). For the experimental condition, the rod-and-box display was presented until the infant met a habituation criterion, defined as a decline in looking time during three consecutive trials, adding up to less than half the total looking time during the first three trials. Timing of each trial began when the infant fixated the screen after display onset. Observers pressed separate buttons so long as the infant fixated the screen and released the buttons when the infant looked away. A trial was terminated when both observers released their buttons for an overlapping 2 s. The screen was then turned off by the computer, and the next display appeared 2 s later. When habituation looking times declined to criterion, the computer changed to test displays. The two test displays were seen three times each in alternation, for a total of six posthabituation trials. For infants in the baseline condition, testing conditions were identical except that the infants were not habituated before viewing the test displays.

Results and Discussion

Looking times were calculated by averaging the two observers' judgments for each test trial. Interobserver agreement was high across infants in the four experiments in this study (mean Pearson $r = .99$). Looking time data in some cells were characterized by positive skew; therefore, all cells were examined for outliers prior to analysis. Any score exceeding 2 *SD* from the mean for its cell was eliminated from the sample (there were 28 outliers across the four experiments in this study, or 3.6% of the total number of scores). Preliminary analyses for all experiments including sex of participant revealed no significant main effects or interactions that bear on the questions of interest (i.e., no sex differences in performance); therefore, subsequent analyses collapsed across this variable.

Figure 5 presents mean looking times during habituation and test. Data were examined for test display preferences with a 2 (Condition: experimental vs baseline) $\times$ 2 (Order: consistent vs inconsistent test display presented first) $\times$ 2 (Display: consistent vs inconsistent) $\times$ 3 (Trial: first, second, or third block of test trials) mixed analysis of variance (ANOVA), yielding a significant main effect of display, $F(1, 28) = 24.14$, $p < .001$, due to an overall preference for the MLI display, and a significant main effect of trial, $F(2, 56) = 28.49$, $p < .001$, due to an overall decline in looking across trials. These main effects were qualified by a significant interaction between condition and trial, $F(2, 56) = 9.82$, $p < .001$, due to a more precipitous decline in looking across trials by infants in the baseline condition. Most important, there was a significant interaction between condition and display, $F(1, 28) = 5.22$, $p < .05$. There were no other significant effects. Simple effects tests revealed longer looking at the MLI test display in the experimental condition, $F(1, 28) = 5.36$, $p < .05$, but not in the baseline condition, $F(1, 28) = 0.84$, *ns*.

In sum, infants in the motion/location consistency experimental condition looked significantly longer at the inconsistent display relative to the consistent display, whereas infants in the baseline condition exhibited no overall preference. These results indicate that some level of unity percepts is available in the habit-

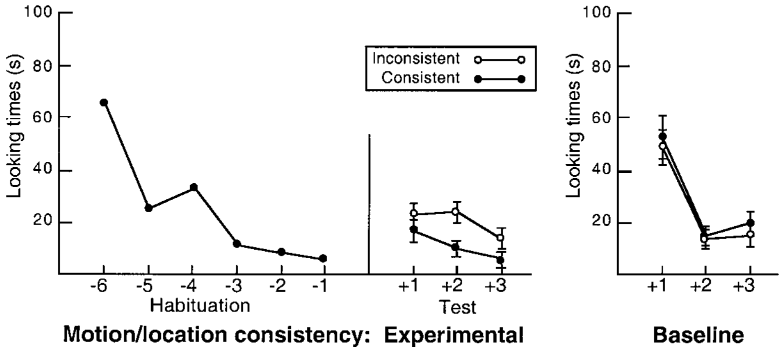


FIG. 5. Looking times during habituation and test in Experiment 1. Error bars represent *SEM*. The 4-month-old infants looked longer at the motion/location inconsistent display, relative to the motion/location consistent display, subsequent to habituation, suggesting that they perceived a violation of the motion and location of the rod parts' intersection. Infants in the baseline (no habituation) condition exhibited no reliable preference.

uation stimulus, despite the misalignment of the rod parts' edges. This is most likely due to the powerful organizing effect of common motion and the fact that our method provides a more sensitive test than has been used in past research.

EXPERIMENT 2: LOCATION CONSISTENCY

The second experiment tested 4-month-olds' perception of object unity with the location consistent and location inconsistent displays (the habituation and LC displays were identical to the habituation and MLC displays, respectively, used in Experiment 1). Recall that the LI display violates the location of the hidden intersection but preserves its motion (see Fig. 4); therefore, unity percepts might not obtain to the same extent as in the first experiment.

Method

Participants. The final sample consisted of 32 full-term infants (16 females and 16 males, mean age = 124.1 days, *SD* = 7.0). The infants were recruited using the same procedures, and from the same population, as in the first experiment.

Apparatus, stimuli, and procedure. All aspects of the apparatus, stimuli, and procedure were identical to those of Experiment 1, with the following exception: In the LI test display, the central rod part was offset by 7.5 cm (4.3°) and thus misaligned with the rod parts; it moved in tandem with the top and bottom rod segments (see Fig. 4).

Results and Discussion

Looking times were again calculated by averaging the two observers' judgments for each test trial. Figure 6 presents mean looking times during habituation and test. Data were examined for test display preferences with a 2 (Condition:

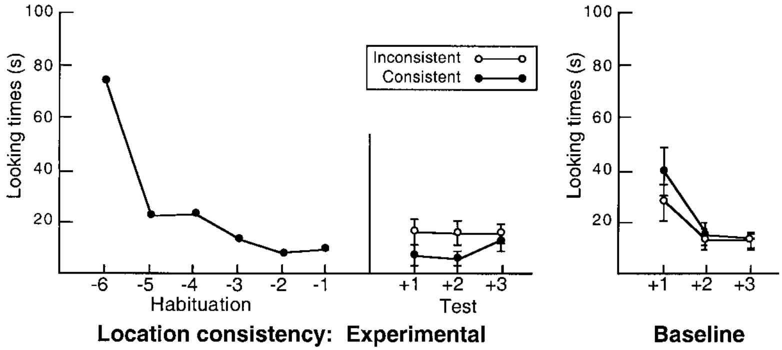


FIG. 6. Looking times during habituation and test in Experiment 2. Error bars represent *SEM*. The 4-month-old infants looked longer at the location inconsistent display, relative to the location consistent display, subsequent to habituation, suggesting that they perceived a violation of the location of the rod parts' intersection, even when it moved in tandem with the top and bottom rod parts. Infants in the baseline (no habituation) condition exhibited no reliable preference.

experimental vs baseline) × 2 (Order: consistent vs inconsistent test display presented first) × 2 (Display: consistent vs inconsistent) × 3 (Trial: first, second, or third block of test trials) mixed ANOVA, yielding a significant main effect of trial, $F(2, 56) = 8.14$, $p < .001$, due to an overall decline in looking across trials. These main effects were qualified by a reliable interaction between condition and trial, $F(2, 56) = 9.38$, $p < .001$, due to a more precipitous decline in looking across trials by infants in the baseline condition. There were also several interactions involving effects of order: between order and display, $F(1, 28) = 5.82$, $p < .05$; among order, display, and trial, $F(2, 56) = 6.23$, $p < .01$, and among condition, order, display, and trial, $F(2, 56) = 5.14$, $p < .05$. These effects of order were due to longer looking at the display presented first by infants in the baseline condition, an effect that was most pronounced in the first block of trials. Most important, there was a reliable Condition × Display interaction, $F(1, 28) = 5.91$, $p < .05$. There were no other significant effects. Simple effects tests revealed longer looking at the LI test display in the experimental condition, $F(1, 28) = 4.16$, $p = .05$, but a nonsignificant tendency to look longer at the LC display by infants in the baseline condition, $F(1, 28) = 1.96$, *ns*.

To explore whether unity percepts were stronger in Experiment 1 (in which both motion and location were violated) than in Experiment 2 (in which location was violated but motion was preserved), the data from the two experimental conditions were subjected to a 2 (Experiment: motion/location vs location consistency) × 2 (Order: consistent vs inconsistent test display presented first) × 2 (Display: consistent vs inconsistent) × 3 (Trial: first, second, or third block of test trials) mixed ANOVA, yielding a significant main effect of display, $F(1, 28) = 17.03$, $p < .001$, due to an overall preference for the inconsistent displays, and a significant main effect of trial, $F(2, 56) = 4.30$, $p < .05$, due to an overall decline in looking across trials. There was also a reliable interaction between experiment and trial, $F(2, 56) = 7.52$, $p < .01$, due to a sharper decline in looking across trials in Experiment 1, and no other significant effects. The key interaction that would reveal differences in performance between the two experimental conditions (the Experiment × Display interaction) was not significant, $F(1, 28) = .008$, *ns*.

In sum, infants in the location consistency experimental condition looked longer at the inconsistent display than at the consistent display, whereas infants in the baseline condition exhibited no overall reliable preference. These results indicate that the infants were highly sensitive to the likely location of the hidden intersection of the rod segments in the habituation display and responded to a violation of this location even when it moved with the upper and lower segments and common motion of all visible parts was maintained. Notably, however, the displacement of the intersection in the LI display was substantial. Experiment 3 was designed to explore young infants' detection of a more subtle violation, one in which both the motion and location of the intersection were preserved and only its orientation was violated.

EXPERIMENT 3: ORIENTATION CONSISTENCY

The third experiment probed 4-month-olds' perception of object unity with the orientation consistent and orientation inconsistent displays (the habituation and OC displays were identical to the habituation and MLC and LC displays, respectively, used in Experiments 1 and 2). Recall that the OI display violates only the orientation of the hidden intersection but preserves both its motion and location (see Fig. 4); therefore, unity percepts might be difficult to achieve for 4-month-olds.

Method

Participants. The final sample consisted of 32 full-term infants (16 females and 16 males, mean age = 128.3 days, $SD = 8.1$). One additional infant was observed but not included in the sample due to equipment failure. The infants were recruited using the same procedures, and from the same population, as in the first two experiments.

Apparatus, stimuli, and procedure. All aspects of the apparatus, stimuli, and procedure were identical to those of Experiments 1 and 2, with the following exception: In the OI test display, the central rod part was oriented 180° horizontally relative to the OC display; it moved in tandem with the top and bottom rod segments (see Fig. 4).

Results and Discussion

Looking times were again calculated by averaging the two observers' judgments for each test trial. Figure 7 presents mean looking times during habituation and test. Data were examined for test display preferences with a 2 (Condition: experimental vs baseline) × 2 (Order: consistent vs inconsistent test display pre-

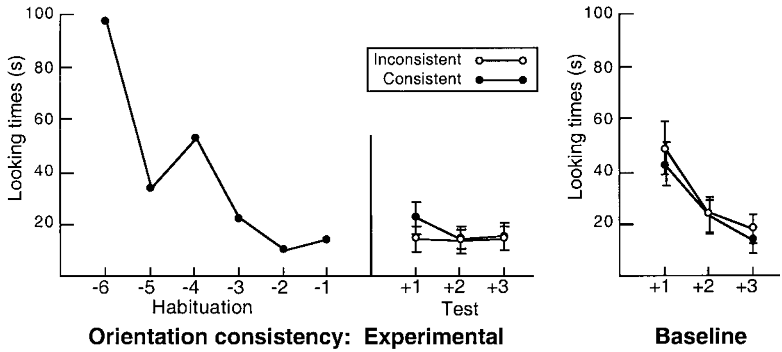


FIG. 7. Looking times during habituation and test in Experiment 3. Error bars represent *SEM*. The 4-month-old infants in both the experimental and baseline (no habituation) conditions showed no reliable test display preference, providing no evidence of perception of the orientation of the rod parts' intersection during habituation.

sented first) × 2 (Display: consistent vs inconsistent) × 3 (Trial: first, second, or third block of test trials) mixed ANOVA, yielding a significant main effect of condition, $F(1, 28) = 12.47$, $p < .01$, due to longer looking overall by infants in the baseline condition, and a significant main effect of trial, $F(2, 56) = 8.63$, $p < .001$, due to an overall decline in looking across trials. There was also a reliable interaction between condition and trial, $F(2, 56) = 4.35$, $p < .05$, due to a more precipitous decline in looking across trials by infants in the baseline condition relative to the experimental condition, and reliable interactions among condition, order, and display, $F(1, 28) = 6.32$, $p < .05$, and among condition, order, display, and trial, $F(2, 56) = 6.42$, $p < .01$. These latter two interactions were a function of the tendency of infants in the baseline condition to look longer at the display presented first, a tendency that declined across trials and was more pronounced than that of infants in the experimental condition. There were no other significant effects. The Condition × Display interaction was not significant, $F(1, 28) = .02$, *ns*, and inspection of Fig. 7 reveals no trend toward longer looking at the OI display by infants in the experimental condition. Therefore, this experiment provides no evidence that the infants perceived or did not perceive the rod parts' unity or the violation of the orientation of the hidden intersection.

To explore whether unity percepts were stronger in Experiments 1 and 2 than in Experiment 3, the data from the three experimental conditions were subjected to a 3 (Experiment: motion/location vs location vs orientation consistency) × 2 (Order: consistent vs inconsistent test display presented first) × 2 (Display: consistent vs inconsistent) × 3 (Trial: first, second, or third block of test trials) mixed ANOVA, yielding a significant main effect of display, $F(1, 42) = 6.33$, $p < .05$, due to a greater preference overall for the inconsistent test displays, and a significant main effect of trial, $F(2, 84) = 3.76$, $p < .05$, due to an overall decline in looking across trials. There was also a reliable Experiment × Display interaction,

$F(2, 42) = 6.28$, $p < .01$, and no other significant effects. Simple effects tests revealed significant preferences for the inconsistent displays by infants in the first two experiments combined, $F(1, 42) = 16.81$, $p < .001$. In the third experiment, there was a slight (but not statistically significant) preference for the OC display, $F(1, 42) = 2.08$, *ns*.

In sum, there is no evidence that the infants detected the violation of the orientation of the hidden intersection of the rod segments in the habituation display. This finding contrasts sharply with the strong evidence from Experiments 1 and 2 that young infants respond to violations in motion and location, and it suggests that the orientation difference may have been too subtle to be picked up by 4-month-olds or that 4-month-olds have no clear expectation of the orientation of the hidden region, provided it is in the correct location and moves along with the other rod segments. In Experiment 4, we asked whether a group of older infants (7-month-olds) would respond to an orientation violation.

EXPERIMENT 4: ORIENTATION CONSISTENCY, 7-MONTH-OLDS

Method

Participants. The final sample consisted of 32 full-term infants (15 females and 17 males, mean age = 216.8 days, $SD = 9.8$). Four additional infants were observed but not included in the final sample due to fussiness. The infants were recruited using the same procedures, and from the same population, as in the first three experiments.

Apparatus, stimuli, and procedure. All aspects of the apparatus, stimuli, and procedure were identical to those of Experiment 3.

Results and Discussion

Looking times were again calculated by averaging the two observers' judgments for each test trial. Figure 8 presents mean looking times during habituation and test. Data were examined for test display preferences with a 2 (Condition: experimental vs baseline) $\times$ 2 (Order: consistent vs inconsistent test display presented first) $\times$ 2 (Display: consistent vs inconsistent) $\times$ 3 (Trial: first, second, or third block of test trials) mixed ANOVA. There were no significant main effects. There was a reliable interaction between condition and display, $F(1, 28) = 5.30$, $p < .05$, which was qualified by a reliable interaction among condition, order, display, and trial, $F(2, 56) = 3.56$, $p < .05$. There were no other significant effects. The four-way interaction was due to the tendency of infants in the baseline condition to look longer overall at the display presented first, a tendency that declined across trials and was more pronounced than that of infants in the experimental condition. Simple effects tests were employed to examine the two-way interaction and revealed reliably longer looking at the OI display by infants in the experimental condition, $F(1, 28) = 9.35$, $p < .01$, but not in the baseline condition, $F(1, 28) = .04$, *ns*.

To explore whether unity percepts were stronger in Experiment 4 than in Experiment 3, the data from the two experimental conditions were subjected to

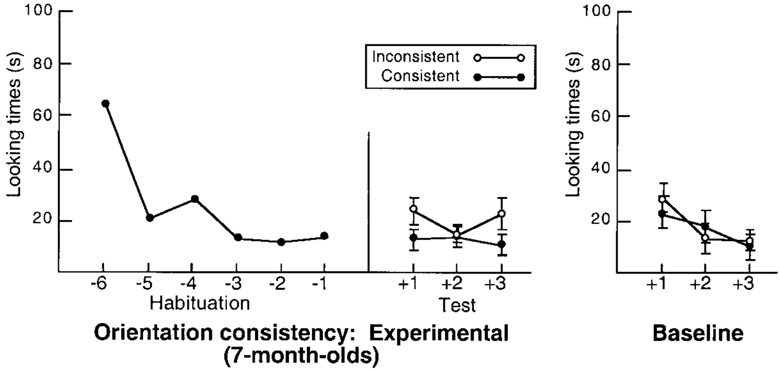


FIG. 8. Looking times during habituation and test in Experiment 4. Error bars represent *SEM*. The 7-month-old infants looked longer at the orientation inconsistent display, relative to the orientation consistent display, subsequent to habituation, suggesting that they perceived a violation of the orientation of the rod parts' intersection, even when motion and approximate location were preserved across habituation and test. Infants in the baseline (no habituation) condition exhibited no reliable preference.

a 2 (Age Group: 4-month-olds vs 7-month-olds in Experiments 3 and 4, respectively) × 2 (Order: consistent vs inconsistent test display presented first) × 2 (Display: consistent vs inconsistent) × 3 (Trial: first, second, or third block of test trials) mixed ANOVA, yielding only one reliable effect, an Age Group × Display interaction, $F(1, 28) = 8.91$, $p < .01$. Simple effects tests revealed longer looking at the OI display by the 7-month-olds, $F(1, 28) = 7.04$, $p < .05$, but not by the 4-month-olds, $F(1, 28) = 2.46$, *ns*.

In sum, Experiment 4 reveals that 7-month-old infants appear to have perceived unity in the rod-and-box display, as reflected by a response to a violation of the expected orientation of the hidden intersection, in contrast to the 4-month-olds in Experiment 3. Therefore, we conclude that there are developments with age in the ability to perceive object unity under the challenging circumstances provided in the current experiment, in particular infants' percepts of the orientation of the hidden region.

GENERAL DISCUSSION

In these experiments, 4-month-old infants were habituated to a rod-and-box display in which the rod edges were misaligned and underwent common motion and subsequently tested for perception of unity of the rod parts by presenting them violations of the appearance of the intersection of the formerly hidden segments. The current experiments are the first to explore together infants' sensitivity to violations of three key components of veridical percepts of partly occluded objects (motion, location, and orientation), and the outcome confirms the suggestion that young infants develop some perceptual biases concerning unity from motion information during habituation to an occlusion display. These biases inform percepts of the nature of the rod parts' expected motion and how they might be connected in a global fashion, but we also obtained important evidence concerning limitations in 4-month-olds' percepts of the precise orientation of the hidden intersection. Only when 7-month-olds were tested for orientation percepts was positive evidence obtained. This subtler form of unity perception, then, likely undergoes developments between 4 and 7 months of age.

Experiments 1, 2, and 4 are the first to document infants' unit formation in the absence of edge alignment or good form to assist in the formation of an impression of a connected, partly occluded object. These results concur with a wealth of evidence on the importance of motion in early perceptual organization (Johnson & Aslin, 1998, 2000; Johnson & Johnson, 2001; Johnson & Mason, 2002; Jusczyk et al., 1999; Kellman, Gleitman, & Spelke, 1987; Kellman & Short, 1987; Kellman & Spelke, 1983; Kellman et al., 1986) but stand in contrast to previous reports of young infants' failures to perceive object unity in displays with misaligned rod edges (Johnson & Aslin, 1996; Johnson et al., 2000). It seems likely that part of the explanation for the disparate results lies in the methods adopted in the current study. The previous reports had probed for a more explicit perceptual representation of the continuity of the rod, a task that is likely to be made more complicated for the infants by the misalignment of the edges. We tested for recognition of the appearance of the hidden region by presenting two possibilities during test: one matching what an adult might posit, in terms of the region's motion, location, and orientation, and the other violating one of these three aspects. Our methods, therefore, appear to comprise a sensitive means of exploring some recognition-based forms of object unity. Young infants provide no evidence of an active perceptual representation of the absent part for this stimulus type (Johnson & Aslin, 1996; Johnson et al., 2000; cf. Smith et al., in press), but in the current experiments they recognized a violation of unity conditions in the form of an "illegitimate" feature rather than a missing one. This recognition-based paradigm is rooted in the assumption that infants exhibit a novelty preference after habituation to a single stimulus, an assumption that has a firm footing in a large empirical base (Bornstein, 1985). The nature of the test displays shown after habituation, however, appears to be crucial in revealing the perceptual competence under investigation.

Our findings also speak to an issue that has received little attention in the literature: the development of infants' perception of the form of a hidden surface that becomes revealed. Termine, Hrynick, Kestenbaum, Gleitman, and Spelke (1987) found that 4.5-month-olds appeared to perceive the background (a textured, flat, vertical surface) as continuous behind a small occluder when the edges of the background appeared to adults to extend indefinitely (in this case, the edges were occluded by the frame of the display apparatus). By contrast, when the same textured surface was presented with clear boundaries behind the occluder against a larger white background, the infants provided no evidence of perceptual completion. Craton (1996) used static displays to explore infants' perception of the global form of a partly occluded object and reported that 8-month-olds, but not 5.5-

or 7-month-olds, seemed to perceive the objects as composed of smooth continuous contours. Together with the findings of the current experiments, these studies concur in the suggestion that perceptual completion in infancy is a gradual process extending throughout most of the first year after birth. Percepts of unity can be achieved early provided that the stimulus meets the young infants' limited perceptual skills by providing sufficiently rich visual information (i.e., some appropriate combination of motion, alignment, global configuration, and depth) (see Johnson, 1997). Perception of hidden form is more fragile, however, and appears to be delayed relative to an overall impression of unity. Moreover, form perception seems to emerge in a fragmented fashion, first encompassing global motion and location and only later encompassing more fine-grained aspects such as the precise orientation.

Our finding of relatively delayed perception of occluded form, and more subtle kinds of unity, is consistent with recent reports of protracted development of integration of information across the visual field. Kovács (2000), for example, reported that contour integration across spatially separated Gabor patches (oriented stimulus elements designed to match receptive field properties of early visual neurons) is not adult-like until after 14 years. This finding was interpreted to arise from immature long-range connectivities in primary visual areas (Burkhalter, Bernardo, & Charles, 1993) and feedback ("top-down") connections from extrastriate cortex that facilitate the use of context to segregate and link local elements in a scene (Burkhalter, 1993). In addition, this finding may reflect inefficient information processing skills such as scanning patterns (Johnson, 2001; Johnson & Johnson, 2001; Kovács, Kozma, Fehér, & Benedek, 1999).

REFERENCES

Arterberry, M. E., & Yonas, A. (2000). Perception of three-dimensional shape specified by optic flow by 8-week-old infants. *Perception & Psychophysics,* **62,** 550–556.

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

Bornstein, M. H. (1985). Habituation of attention as a measure of visual information processing in human infants: Summary, systematization, and synthesis. In G. Gottlieb & N. A. Krasnegor (Eds.), *Measurement of audition and vision in the first year of postnatal life: A methodological overview* (pp. 253–300). Norwood, NJ: Ablex.

Burkhalter, A. (1993). Development of forward and feedback connections between areas V1 and V2 of human visual cortex. *Cerebral Cortex,* **3,** 476–487.

Burkhalter, A., Bernardo, K. L., & Charles, V. (1993). Development of local circuits in human visual cortex. *Journal of Neuroscience,* **13,** 1916–1931.

Craton, L. E. (1996). The development of perceptual completion abilities: Infants' perception of stationary, partly occluded objects. *Child Development,* **67,** 890–904.

Ghim, H.-R. (1990). Evidence for perceptual organization in infants: Perception of subjective contours by young infants. *Infant Behavior and Development,* **13,** 221–248.

Johnson, S. P. (1997). Young infants' perception of object unity: Implications for development of attentional and cognitive skills. *Current Directions in Psychological Science,* **6,** 5–11.

Johnson, S. P. (2000). The development of visual surface perception: Insights into the ontogeny of knowledge. In C. Rovee-Collier, L. Lipsitt, & H. Hayne (Eds.), *Progress in infancy research* (Vol. 1, pp. 113–154). Mahwah, NJ: Erlbaum.

Johnson, S. P. (2001). Visual development in human infants: Binding features, surfaces, and objects. *Visual Cognition*, **8**, 565–578.

Johnson, S. P., & Aslin, R. N. (1995). Perception of object unity in 2-month-old infants. *Developmental Psychology*, **31,** 739–745.

Johnson, S. P., & Aslin, R. N. (1996). Perception of object unity in young infants: The roles of motion, depth, and orientation. *Cognitive Development*, **11,** 161–180.

Johnson, S. P., & Aslin, R. N. (1998). Young infants' perception of illusory contours in dynamic displays. *Perception*, **27,** 341–353.

Johnson, S. P., & Aslin, R. N. (2000). Infants' perception of transparency. *Developmental Psychology*, **36,** 808–816.

Johnson, S. P., Bremner, J. G., Slater, A., & Mason, U. (2000). The role of good form in young infants' perception of partly occluded objects. *Journal of Experimental Child Psychology*, **76,** 1–25.

Johnson, S. P., Cohen, L. B., Marks, K., & Johnson, K. L. (2001). *Young infants' perception of object unity in rotation displays*. Unpublished manuscript, Cornell University.

Johnson, S. P., & Johnson, K. L. (2001). Early perception–action coupling: Eye movements and the development of object perception. *Infant Behavior and Development*, **23,** 461–483.

Johnson, S. P., & Mason, U. (2002). Perception of kinetic illusory contours by 2-month-old infants. *Child Development*, **73,** 22–34.

Jusczyk, P. W., Johnson, S. P., Spelke, E. S., & Kennedy, L. J. (1999). Synchronous change and perception of object unity: Evidence from adults and infants. *Cognition*, **71,** 257–288.

Kellman, P. J. (1993). Kinematic foundations of infant visual perception. In C. E. Granrud (Ed.), *Visual perception and cognition in infancy* (pp. 121–173). Hillsdale, NJ: Erlbaum.

Kellman, P. J., & Arterberry, M. E. (1998). *The cradle of knowledge: Development of perception in infancy*. Cambridge, MA: MIT Press.

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., & Shipley, T. F. (1991). A theory of visual interpolation in object perception. *Cognitive Psychology*, **23,** 141–221.

Kellman, P. J., & Short, K. R. (1987). Development of three-dimensional form perception. *Journal of Experimental Psychology: Human Perception and Performance*, **13,** 545–557.

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,** 72–86.

Koffka, K. (1935). *Principles of Gestalt psychology*. London: Routledge & Kegan Paul.

Kovács, I. (2000). Human development of perceptual organization. *Vision Research*, **40,** 1301–1310.

Kovács, I., Kozma, P., Fehér, Á., & Benedek, G. (1999). Late maturation of visual spatial integration in humans. *Proceedings of the National Academy of Sciences*, **96,** 12204–12209.

Nakayama, K., He, Z. J., & Shimojo, S. (1995). Visual surface representation: A critical link between lower-level and higher-level vision. In S. M. Kosslyn & D. N. Osherson (Eds.), *Visual cognition*, Vol. 2: *An invitation to cognitive science* (2nd ed., pp. 1–70). Cambridge, MA: MIT Press.

Needham, A. (1998). Infants' use of featural information in the segregation of stationary objects. *Infant Behavior and Development*, **21,** 47–75.

Smith, W. C., Johnson, S. P., & Spelke, E. S. (in press). Motion and edge sensitivity in perception of object unity. *Cognitive Psychology*.

Termine, N., Hrynick, T., Kestenbaum, R., Gleitman, H., & Spelke, E. S. (1987). Perceptual completion of surfaces in infancy. *Journal of Experimental Psychology: Human Perception and Performance*, **13,** 524–532.

Received December 11, 2000; revised December 18, 2001