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The Role of Good Form in Young Infants' Perception of Partly Occluded Objects

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Young infants have been reported to perceive the unity of a center-occluded object when the visible ends of the object undergo common motion, but not on the basis of stationary information (e.g., P. J. Kellman & E. S. Spelke, 1983). We investigated the possibility that 4-month-old infants will attend to and utilize the global configuration (i.e., the "good form") of a partly occluded, moving object to perceive its unity and coherence behind the occluder. In the first experiment, infants viewed a partly occluded circle or cross that translated laterally. Infants who habituated in the minimum number of trials ("fast habituators") showed a reliable posthabituation preference for a broken object over a complete object, indicating perception of unity in the habituation display. Slow habituators exhibited no posthabituation preference. In the second experiment, infants were presented with small ring and cross displays, and the infants looked longer at the broken object. There were no reliable differences in performance between fast and slow habitu-

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ators. A control group demonstrated no reliable posthabituation preference. In three additional conditions, infants viewed either a partly occluded half ring or a display in which two rod parts were either relatable and nonaligned or nonrelatable. The results indicated that curvature per se provided information in support of completion, in addition to global configuration and motion. Implications for theories of infants' visual development are discussed.

Key Words: cognitive development; infant perception; Gestalt; object perception; vision.

Our visual world is complex, filled with objects at various distances from the observer. We do not have direct visual access to the entirety of most objects' surfaces, because parts of many surfaces are occluded by other, nearer objects. Nevertheless, our perceptual experience is generally one of bounded, coherent, segregated entities, whose surfaces continue beyond the point where they are directly visible, and whose shapes are typically smooth and regular (cf. Biederman, 1987; Marr, 1982). That is, visual perception is organized into percepts that are less complex than the visible surface array.

These observations led the Gestalt psychologists, earlier in this century, to posit that perceptual experience corresponds to the simplest and most regular interpretation of a particular visual array (the so-called minimum principle), consistent with a general law of Prägnanz stipulating that perceptual organization is as "good" as allowed by the prevailing conditions (Koffka, 1935). For example, in the array depicted in Fig. 1A, an adult observer will usually report perception of a center-occluded rod behind a nearer, occluding box, rather than two aligned rod parts that happen to move together. This determination is made on the basis of the alignment of rod edges across the occluder (the Gestalt principle of good continuation), the resemblance of the two visible rod surfaces (symmetry and similarity), the regularity and simplicity of the rod's shape (good

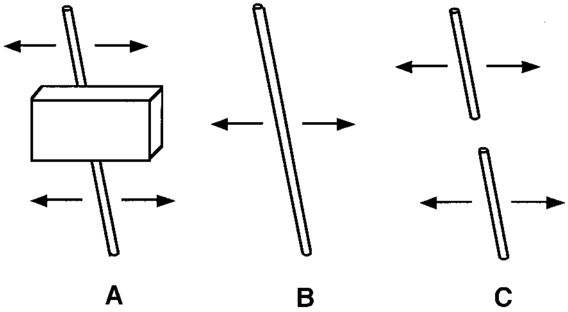

FIG. 1. Displays employed in past research to investigate young infants' perception of partly occluded objects (adapted from Kellman & Spelke, 1983). A: A partly occluded rod moves relative to a stationary occluder. B: Complete rod. C: Broken rod. After habituation to A, infants showed a preference for C relative to B, indicating perception of the rod's unity in A. A control group preferred neither test display.

form), and the common motion of the visible rod surfaces (common fate). The minimum principle and Prägnanz were thought to arise from a tendency of neural activity toward minimum work and minimum energy (analogous to other physical systems), which drives the visual system toward the simplicity (Koffka, 1935).

Because this predisposition is inherent in the visual system, according to the Gestalt view, it follows that young infants should experience the visual array in ways similar to adults. Evidence for this proposal has been mixed. Spelke (1990; Spelke & Van de Walle, 1993) described research examining the contributions of Gestalt principles to infants' perceptual organization of three-dimensional object arrangements, with negative outcomes. Using reaching or preferential looking paradigms, these studies explored infants' skills at perceiving either object boundaries, in displays consisting of two separated, adjacent, or overlapping objects, or object unity, in displays consisting of two surfaces protruding from behind an occluder. In object boundary experiments, clear evidence of surface segregation was obtained only when there was a detectable spatial gap between objects (e.g., Kestenbaum, Termine, & Spelke, 1987) or when one object moved relative to the other (e.g., Spelke, Hofsten, & Kestenbaum, 1989). In object unity experiments, evidence of unit formation behind the occluder was obtained only when the surfaces underwent common motion (Kellman & Spelke, 1983). Unit formation was blocked, however, when spatial information indicated disjoint objects (e.g., when two separate rod parts were visible in front of the occluder). Across experiments, infants did not appear to achieve surface segregation or unit formation by analyzing surface features such as the shapes, patterns, or colors of objects, information that adults use to determine segregation or unity. That is, infants did not appear to take account of the available stationary, configurational information in the displays.

Infants' responses to Gestalt information have also been tested with more simple, two-dimensional displays, with positive results. For example, Van Giffen and Haith (1984) found that 3-month-olds detected a discrepant element in an array of line segments arranged in a circle or square shape, suggesting that the infants were sensitive to good continuation. Likewise, Quinn, Brown, and Streppa (1997) reported that 3- and 4-month-olds organized displays containing overlapping shapes (either a teardrop and a square or a circle and a square) in a manner consistent with good continuation, rather than other potential configurations, and Ghim (1990) obtained some evidence for perception of illusory contours in 3- and 4-month-olds, also consistent with good continuation. In addition, Quinn, Burke, and Rush (1993) found that the Gestalt principle of similarity appeared to be accessible by 3 months of age: The infants grouped discrete pattern elements into rows or columns according to the elements' lightness.

Stimulus complexity may underlie the conflict between these sets of results. Needham has explored systematically the development of infants' use of various information sources in segregating three-dimensional objects (see Needham, 1997; Needham, Baillargeon, & Kaufman, 1997, for reviews). Evidence was obtained that young infants attend to differences in surface shape, color, and texture when segregating objects in displays consisting of a simple object layout (Needham, 1998). In more complex displays, composed of objects with irregular edges or multiple overlapping boundaries between objects, infants' veridical responses to object layout appeared to be compromised. Evidence was also obtained that young infants' segregation skills can be enhanced by providing prior experience with object displays (Needham & Baillargeon, 1998). If displays are too complex, therefore, information-processing skills may be taxed to the point of ineffectiveness at determining depth relations and object boundaries (Needham et al., 1997). Infants' use of various sources of visual information thus appears to depend in part on the complexity of the task, as well as on the specific information in question.

The present experiments also explored stimulus complexity and regularity, continuing work originally described by Bower (1967) and Kellman and Spelke (1983) to investigate information sources contributing to infants' perception of object unity. Kellman and Spelke presented 4-month-old infants with the display depicted in Fig. 1A until habituation (i.e., looking times declined to a preset criterion). The infants were then shown two test displays, in alternation, consisting of a complete rod (Fig. 1B) and a "broken" rod, two rod parts with a gap between them (Fig. 1C). Although both displays were consistent with the visible portions of the rod in the habituation display, the infants exhibited a significant preference for the broken rod. Given that young infants reliably prefer novel stimuli after habituation (Bornstein, 1985; Spelke, 1985), this result suggests that the complete rod was relatively familiar, and the broken rod relatively novel. The results of control experiments provided evidence that infants have no inherent preference for a broken rod. Kellman and Spelke therefore concluded that the infants who viewed the rod-and-box display perceived the connectedness of the rod.

Information for the rod parts' connectedness was available from similarity, good form, good continuation, and common motion, but not all these principles appeared to contribute to perception of object unity in the Kellman and Spelke (1983) experiments. In stationary displays, for example, 4-month-olds did not appear to perceive unity, despite the presence of good form and good continuation. However, when rod surfaces underwent common motion, either laterally, vertically, or in depth, the infants seemed to perceive unity (Kellman, Spelke, & Short, 1986). This outcome extended to a display in which a rod part protruded from behind the top of an occluder, and a dissimilar, irregularly shaped polygon protruded from the bottom; the rod and polygon underwent common lateral motion. These results were interpreted to reflect the primacy of motion to the development of object perception (Kellman, 1996).

Johnson and Aslin (1996) investigated 4-month-olds' use of stationary con-

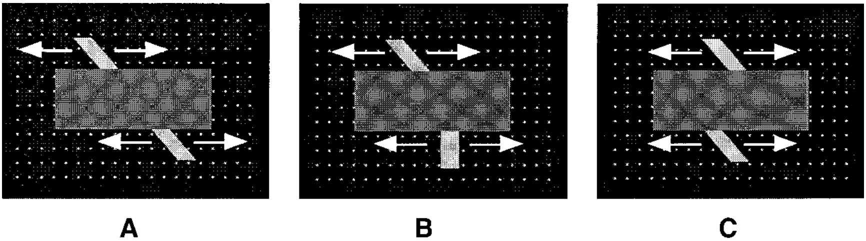

FIG. 2. Displays employed to investigate the role of edge orientation in young infants' perception of objects (Johnson & Aslin, 1996). A: Rod parts are aligned across the occluder. B: Rod parts are not aligned, but are relatable (if extended, they would meet behind the occluder). C: Rod parts are neither aligned nor relatable. Infants appeared to perceive unity only in A. Responses to C indicated perception of disjoint rod parts. Responses to B were intermediate between perception of unity and disjoint rod parts. These results suggest that common motion alone fails to specify unity: Edges must be aligned in order for perception of object unity to occur.

figurational information with an object unity task, employing displays in which the orientations of the rod edges across the occluder were not aligned (i.e., there was no good continuation). This study was motivated by the Kellman (1996; Kellman & Shipley, 1991) proposal of a two-process theory of perceptual unit formation. The *primitive* process takes account of common motion of visible surfaces in determining their unity, but is insensitive to the orientations of edges that lead behind an occluder. The *rich* process takes account of edge orientations as well as their motions. Edges will be perceived as unified if they are *relatable* when interpolated (perceptually extended) behind the occluder. Edges are defined as relatable if they can be connected with a smooth, monotonic curve behind the occluder (see Kellman & Shipley, 1991, for details). According to Kellman (1996), only the primitive process is operational in infants younger than 6 months of age. The two-process theory, therefore, predicts that two surfaces extending from behind an occluder will be perceived as unified by 4-month-olds if the surfaces undergo common motion, regardless of the orientations of their edges.

In contradiction to the two-process theory, Johnson and Aslin (1996) reported that 4-month-olds appeared to perceive unity in rod-and-box displays only when the edges of the rod surfaces were aligned across the occluder (see Fig. 2A): The infants looked significantly longer at a broken rod following habituation to this display. In a display in which the rod parts were relatable but not aligned (Fig. 2B), however, the infants did not demonstrate a consistent posthabituation preference. In a display in which the rod parts were neither relatable nor aligned (Fig. 2C), the infants appeared to perceive them as disjoint objects, looking longer at a complete rod test display. These results obtained even though the rod parts underwent common, lateral motion in all three displays. The edge relations in these displays, therefore, appeared to have crucial inputs into the unit formation process.

Johnson and Aslin (1996) suggested that rather than relying on a single source of information (such as motion) to the exclusion of others, young infants will attend to and utilize a range of information to accomplish perceptual segregation of surfaces and unit formation (as do adults; see Cutting & Vishton, 1995). Johnson and Aslin proposed a “threshold” model, stipulating that veridical object perception is achieved when *sufficiency* of visual information is met with *efficiency* of perceptual and cognitive skills (see also Johnson, 1997). The threshold model cannot be used to predict which cues will be used in a particular perceptual task, but testable hypotheses can be drawn from this approach, some of which have been supported empirically. For example, Johnson and Náñez (1995) reported that 4-month-olds demonstrated robust responses to object unity, showing a consistent posthabituation preference for a broken rod relative to a complete rod. In contrast, 2-month-olds exhibited no posthabituation preference. Johnson and Aslin (1995) hypothesized that given additional perceptual support, 2-month-olds might perceive object unity. This was accomplished with rod-and-box displays in which more of the rod surface was visible, relative to the display employed by Johnson and Náñez. The prediction was confirmed: A consistent posthabituation preference for the broken rod indicated perception of object unity in the “enhanced” displays. Johnson and Aslin (1996), moreover, reported that motion of collinear edges alone is not sufficient to support young infants’ perception of object unity: When shown a partly occluded rod in a two-dimensional display that lacked background texture (which provides information for depth ordering of visible surfaces), 4-month-olds preferred neither a broken rod nor a complete rod test display. Only when several information sources were available simultaneously was such a preference obtained. The threshold model, therefore, suggests a strategy for investigating the development of perceptual organization: By manipulating the information sources available in a particular visual display, and comparing infants’ responses across displays and across ages, we can gain insights into the means by which young infants achieve surface segregation and unit formation.

The present experiments explored further the role of stationary configurational information in object unity tasks by testing predictions drawn from the threshold model. Specifically, we asked whether 4-month-olds will perceive the unity of objects whose contours are inconsistent with unity at a local level (i.e., their edges are not aligned across the occluder) but whose global shape embodies good form. That is, we added good form to displays of the type employed by Johnson and Aslin (1996), which provided evidence that young infants are sensitive to stationary configurational information in object perception tasks: When such information is inconsistent with a partly hidden object with smooth contours and a regular shape, perception of object unity is blocked. We hypothesized that good form would provide additional information in support of unit formation, given that good form encompasses “continuation . . . resulting in a good whole or good configuration” (Wertheimer, 1923/1958, p. 129). We also considered the question of individual differences in infants’ responses to global and local information with targeted data analyses.

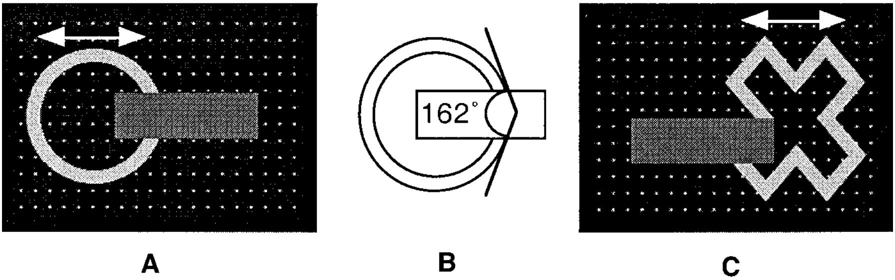

FIG. 3. Displays employed in Experiment 1. A: Ring display. B: Schematic depiction of the relatability of the ring's tangents at the ring–occluder intersection: These tangents would meet at an angle of 162° and are therefore relatable, but not aligned. C: Cross display.

EXPERIMENT 1

The Johnson and Aslin (1996) displays served as a starting point for constructing the displays employed in Experiment 1. Figure 3A depicts a partly occluded *ring* display. The ring's tangents at the intersection of the outer edge and the box, if extended behind the occluder, would be relatable but not aligned (see Fig. 3B). This display is therefore similar, at a local level, to the Johnson and Aslin display depicted in Fig. 2B, which contains edges that are relatable but not aligned. At a global level, however, added surface area in the shape of a circle comprises good form (the circle also provides closure, an additional Gestalt organizational principle). Figure 3C depicts a partly occluded *cross* display. At the intersection of the cross and the box, the edges of the cross are neither relatable nor aligned, and are therefore similar, at a local level, to the Johnson and Aslin display depicted in Fig. 2C. At a global level, like the ring display, added surface area in the shape of a cross embodies good form. We hypothesized that if young infants are able to capitalize on the additional visual information in support of the unity of the ring and cross shapes, they would exhibit posthabituation preferences for a broken ring and a broken cross, respectively, relative to a complete ring or a complete cross. That is, if infants attend primarily to the local information at the object–occluder intersections, we would expect a replication of the Johnson and Aslin results, in that in neither condition would the infants perceive object unity. In contrast, if infants attend to the global object form, and utilize it to perceive a unified, coherent object, we would expect to obtain evidence that the infants perceived object unity in both conditions.

Method

Participants. The final sample consisted of 32 full-term infants (18 female; *M* age = 125 days, *SD* = 7.9). Ten additional infants were observed but not included in the sample due to excessive fussiness (9 infants) or equipment failure (1 infant). The infants were recruited by hospital visits and follow-up telephone calls. The majority of the infants were from Caucasian, middle-class families (the data were collected in Lancaster, in the north of England, an area that is characterized by a low minority population). Parents were paid a nominal sum for their participation.

Apparatus and stimuli. An Amiga 3000 computer and an 80-cm Barco color monitor were used to generate the displays. Two observers, blind to the stimulus on the screen at any given time, viewed the infant through small peepholes cut into two black panels that extended 45 cm from the sides of the monitor. The computer presented the stimulus displays, stored each observer's data, calculated the habituation criterion for each infant, and changed displays after the criterion was met. The computer also recorded how long the infant looked at each display, according to the observers' judgments. These judgments were entered via handheld buttons, connected to the computer's mouse port.

The ring display consisted of a computer-generated 26 × 7.8-cm blue box, subtending 14.6 × 4.5° visual angle (at the infants' 100-cm viewing distance). The box was oriented with its long axis horizontal. A green ring, its outer diameter 23.7 cm (13.3°), underwent lateral translation at a rate of 3.8 cm/s (2.2°/s). The right center portion of the ring appeared to be occluded by the box (see Fig. 3A). The tangents of the circle at its intersections with the box, if extended, would meet at an angle of approximately 162°. The ring and box were presented against a textured background, consisting of a regular 12 × 20 grid of white dots measuring 51 × 36.5 cm (27.0 × 20.0°). Test displays consisted of a complete ring and a broken ring with a gap at the place where the ring in the habituation display had been occluded by the box. Thus both test displays were consistent with the visible portion of the ring in the habituation display. The broken and complete rings moved in the same pattern and at the same rate as the partly occluded ring, and were presented against the same textured background.

The cross display contained a 28 × 28 cm (15.6 × 15.6°) green cross, oriented diagonally, translating laterally so that it was partially occluded by a box (see Fig. 3C). The rate of translation of the cross, size of the occluder, and background were the same as that of the ring display. The edges of the cross, at the point of intersection with the box, would be neither relatable nor aligned, if extended behind the box. Analogous to the ring condition, test displays consisted of a complete cross and a broken cross with a gap at the place where the cross in the habituation display had been occluded by the box. Again, therefore, both test displays were consistent with the visible portion of the cross in the habituation display.

Procedure. Each infant was placed in a car seat and tested in a darkened room. Infants were randomly assigned to either the ring or the cross condition, and to one of the two test display orders (broken or complete object first after habituation). The habituation display was presented until the infant met a habituation criterion. This criterion was defined according to the common "infant-control" procedure (Horowitz, Paden, Bhana, & Self, 1972) 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, during both habituation and test, began when the infant fixated the screen after display onset. Each observer independently indicated how long the infant looked at the display by pressing a separate button as long as the infant fixated the screen, and releasing when the infant looked away (for 14 of the 128 infants across all studies in this report, only one observer was available). An individual trial was terminated when both observers released their buttons for two overlapping seconds. At this point, the screen was turned off by the computer, and the next display appeared 2 s later. When looking times to the habituation display declined to criterion, the computer changed from habituation to test displays. The two test displays were seen three times each in alternation, for a total of six posthabituation trials.

Results and Discussion

Looking times were calculated by averaging the two observers' judgments for each test trial. Interobserver agreement was high (M Pearson $r = .98$ across all experiments, calculated by comparing the two observers' judgments for each trial). Looking time data across cells were somewhat heterogeneous, leading to positive skew in some cells. Therefore data in this and all subsequent experiments were log-transformed prior to analysis. (Analyses were also conducted with nontransformed data, resulting in outcomes with similar interpretations, but with some tests of significance only reaching more marginal levels. Table 1 includes only raw data.)

Table 1 presents the nontransformed mean looking times on the last habituation trial and on the six test trials, collapsed across trial block. There was a tendency for infants to prefer the broken object during test, and they recovered interest (relative to the habituation display) somewhat more to the broken object than to the complete object. Preliminary ANOVAs including sex and order revealed no significant main effects or interactions involving these variables, and data were collapsed across sex and order for subsequent analyses.

Looking times during the six posthabituation test trials were examined with a 2 (condition: ring vs cross) × 2 (display: broken vs complete object during test) × 3 (trial block: first, second, or third pair of test displays) mixed ANOVA. There was a significant effect of display, $F(1, 30) = 8.66$, $p = .0062$, resulting from greater looking overall at the broken test objects than at the complete objects. There was also a significant effect of trial block, $F(2, 60) = 3.24$, $p = .046$, arising from a decline in looking during the last trial block. The effect of condition did not reach significance, $F(1, 30) = .15$, $p = .70$, nor did the Condition × Display interaction, $F(1, 30) = .06$, $p = .81$, the Condition × Trial Block interaction, $F(2, 60) = 1.50$, $p = .23$, the Display × Trial Block interaction, $F(2, 60) = .31$, $p = .73$, or the Condition × Display × Trial Block interaction, $F(2, 60) = 1.42$, $p = .25$.

Planned comparisons (Display × Trial Block ANOVAs) explored differences

TABLE 1
Means of Infants' Looking Times (in Seconds) during the Last Two Habituation Trials and Test Trials

	Habituation	Broken object	Complete object
	Experiment 1		
Ring	13.18 (6.52)	25.11 (5.11)	24.62 (7.10)
Cross	16.26 (5.79)	21.06 (4.02)	17.09 (3.78)
Mean	14.72 (4.30)	23.08 (3.22)	20.86 (1.83)
	Experiment 2		
Small ring	8.56 (1.67)	28.18 (8.25)	22.04 (8.39)
Small cross	12.18 (1.75)	27.63 (6.32)	15.42 (3.35)
Mean	10.37 (1.23)	27.91 (5.11)	18.73 (4.48)
Control (small ring)	24.93 (16.78)	18.82 (2.94)	21.63 (3.91)
Control (small cross)	24.93 (16.78)	20.45 (3.94)	19.06 (3.97)
Mean		19.64 (2.51)	20.35 (2.70)
Half ring	6.88 (1.77)	14.37 (2.84)	7.67 (1.54)
Relatable parts	8.27 (3.58)	10.28 (2.38)	10.61 (2.54)
Nonrelatable parts	6.86 (1.68)	10.14 (2.30)	10.77 (1.95)

Note. These numbers represent raw scores. Analyses reported in the text were computed on log-transformed scores. Standard errors are shown in parentheses.

in preference for the test objects separately for the ring and cross conditions. For the ring condition, there was a marginally significant preference for the broken ring, $F(1, 15) = 4.15$, $p = .060$. The effect of trial block did not reach significance, $F(2, 30) = 1.22$, $p = .31$, nor did the Display × Trial Block interaction, $F(2, 30) = 1.31$, $p = .28$. For the cross condition, there was a marginally significant preference for the broken cross, $F(1, 15) = 4.52$, $p = .051$, and a significant effect of trial block, $F(2, 30) = 4.44$, $p = .021$, the result of a decline in interest across test trials. The Display × Trial Block interaction failed to reach significance, $F(2, 30) = .29$, $p = .75$.

Infants' recovery of looking to each test display was explored via a 2 (condition: ring vs cross) × 3 (display: habituation, broken object, or complete object) ANOVA comparing the mean of the last habituation trial with the means of the three trials of each test display. There was a significant effect of display, $F(2, 60) = 9.86$, $p < .001$. The effect of condition was not significant, $F(1, 30) = .0009$, $p = .98$, nor was the Condition × Display interaction, $F(2, 60) = 1.59$, $p = .21$. Post hoc tests (Tukey HSD) revealed significant recovery of interest both to the broken objects, $p < .001$, and to the complete objects, $p = .0075$.

Planned comparisons (single-variable ANOVAs) explored recovery separately for the ring and cross conditions. For the ring condition, there was a significant difference in looking time across the habituation and test trials, $F(2, 30) = 8.08$,

$p = .0016$. Tukey HSD tests revealed significant recovery both to the broken ring, $p = .0027$, and to the complete ring, $p = .0079$. For the cross condition, there was a marginally significant difference in looking times across habituation and test trials, $F(2, 30) = 2.70$, $p = .084$. There was marginally significant recovery of interest to the broken cross, $p = .068$, but not to the complete cross, $p = .55$ (Tukey HSD).

The possibility of an inherent preference for one of the test displays was not addressed directly in Experiment 1, but several lines of evidence mitigate against the likelihood of such a preference in the present experiment. First, control conditions in past studies of infants' perception of object unity have consistently resulted in a lack of preference for either a broken or a complete object test display (Johnson & Aslin, 1995, 1996, 1998; Johnson & Náñez, 1995; Kellman & Spelke, 1983; Kellman et al., 1986; Slater et al., 1990); there is little reason to suspect such a preference would be observed here. Second, a control condition was included in Experiment 2 with displays similar to those used in Experiment 1, resulting in no reliable test display preference.

Under the assumption that infants have no inherent preference for the broken over the complete object test displays, the findings of Experiment 1 begin to provide evidence that 4-month-old infants may perceive the unity and coherence of partly occluded objects by analyzing and utilizing the objects' global shape. After habituation to a partly occluded ring or cross display, infants preferred a broken ring or cross, respectively, relative to a complete ring or cross. These results obtained despite the fact that the edges of the object at the intersection with the occluder were misaligned (ring) or nonaligned (cross), conditions that have obstructed perception of object unity in rod-and-box displays (Johnson & Aslin, 1996). Notably, however, these results were not robust relative to past reports of perception of object unity (e.g., Johnson & Aslin, 1995, 1996; Johnson & Náñez, 1995; Kellman & Spelke, 1983), suggesting limitations in young infants' full use of available information for unity in the ring and cross displays. Potential reasons for these limitations are explored in Experiment 2.

Individual differences in utilization of global vs local information. Colombo and colleagues have investigated individual differences in 4-month-olds' discrimination of visual stimuli on the basis of global vs local stimulus characteristics. Infants who are "short lookers," so called because they exhibit spontaneously low levels of inspection time to a pretest stimulus, seem to utilize global information in preference to local information after relatively short stimulus exposure times (cf. Ghim & Eimas, 1988). In contrast, "long lookers" require longer exposures to respond to global information (Freeseman, Colombo, & Coldren, 1993). Colombo, Freeseman, Coldren, and Frick (1995) demonstrated a global-to-local processing sequence in short lookers, but reported that long lookers' responses appeared to be dominated by local properties (cf. Stoekler, Colombo, Frick, & Allen, 1998). Moreover, there have been reports of superior performance on cognitive tasks by infants who are "fast habituators" (i.e., infants who habituate more rapidly) relative to “slow habituators” (e.g., Baillargeon, 1987).

These findings suggest that in the context of the present experiment, not all infants will respond equivalently to global stimulus properties, and that an exploration of individual differences may shed light on the issue of success or failure to capitalize on good form in object perception tasks. This was accomplished by categorizing infants into two groups on the basis of habituation performance, and comparing the groups’ test display preferences. Fast habituators ($n = 18$) were defined as those infants who habituated after six trials (the minimum permissible under our criterion), and slow habituators as those who took seven or more trials to habituate ($n = 14$). A 2 (condition) × 2 (trials to habituate: fast vs slow) × 2 (display) × 3 (trial block) mixed ANOVA revealed main effects of display and trial block (discussed previously) and a significant Trials × Display interaction, $F(1, 28) = 4.23$, $p = .049$. Fast habituators exhibited a significant preference for the broken objects relative to the complete objects, as revealed by a Tukey HSD test, $p = .0065$ (*M* looking time to broken objects = 28.07 s, *SEM* = 4.47; *M* looking time to complete objects = 24.57 s, *SEM* = 6.60). In contrast, short habituators preferred neither test display (*M* looking time to broken objects = 16.67 s, *SEM* = 4.15; *M* looking time to complete objects = 16.08 s, *SEM* = 3.39). Interestingly, the infants who habituated in fewer trials looked longer during test, although the difference was not statistically significant, two-tailed $t(30) = 1.51$, $p = .14$. These results indicate that the fast habituators seem to have attended to the global form of the partly occluded circle and cross. In contrast, neither global nor local information appeared to dominate for the short habituators. Additional analyses were conducted in which short and long lookers were defined according to total habituation times and peak fixation duration during habituation trials, but these analyses did not yield significant results.

In summary, some evidence was obtained in Experiment 1 for infants’ use of good form to perceive the unity of partly occluded objects. Tests of individual differences revealed that infants who habituated in fewer trials exhibited a stronger pattern of performance, consistent with the suggestion that fast habituators achieved unit formation in the displays, whereas slow habituators were unable to perceive object unity. There was no evidence for a reliance on local information on the part of any group of infants. Instead, the differences seemed to lie in how effective was the global information in the task of perceiving object unity.

EXPERIMENT 2

The findings of Experiment 1 suggest that, under some circumstances, young infants use global information to perceive the shape of partly occluded objects. Our next experiment asked whether infants might use good form more reliably across a sample of 4-month-olds, including slow habituators. We reasoned that

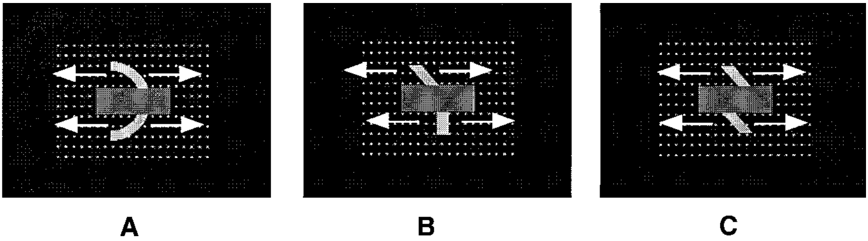

FIG. 4. Displays employed in Experiment 2. A: Half ring display. B: Relatable parts display. C: Nonrelatable parts display. The visible rod parts underwent common motion in each display.

one potential obstacle to utilization of global information might have been the size of the displays employed in Experiment 1. If the ring and cross displays were to be reduced in size, this might effect a shift toward stronger reliance on global information in perception of object unity. Young infants' visual attention often appears to be restricted in large part to central vision (Maurer & Lewis, 1998), leading to the prediction that in smaller displays, global attributes of the stimuli would be more readily discernible (cf. Johnson, 1997; Johnson & Aslin, 1995). This was accomplished in Experiment 2 by replicating the methods of Experiment 1 with partly occluded *small ring* and *small cross* displays. An additional control condition explored the possibility of an inherent preference for the broken objects, by habituating infants to a stimulus (a happy face), presumably unrelated to the partly occluded ring and cross, prior to presentation of the broken and complete test displays.

A subsidiary goal of Experiment 2 was to investigate further the necessary figural properties needed for young infants' perception of object unity. This was accomplished by presentation of partly occluded object segments in isolation, above and below the occluder. The *half ring* display consisted of two curved rod parts, equivalent to half the small ring of Experiment 2 (see Fig. 4A). The half ring stimulus provides a test of whether a curved contour (as opposed to the complete, closed shape of the ring) is sufficient to provide conditions necessary for perception of object unity. The *relatable parts* display consisted of two rod segments whose edges were relatable but not aligned (Fig. 4B). The half ring and relatable parts displays were similar in that at the intersection with the occluder, the edges of the rod parts (or the tangents of the curved rod parts, in the case of the half ring display) were relatable, but not aligned, in both displays. The *nonrelatable parts* display consisted of two nonrelatable, nonaligned rod parts (Fig. 4C), similar in size and orientation to the segments of the small cross that were adjacent to the occluder. (The relatable parts and nonrelatable parts displays were similar to the displays employed by Johnson & Aslin, 1996, depicted in Figs. 2B and 2C, to probe the role of edge orientation in object perception, although the displays used in the present experiment were reduced in size.) The relatable parts and nonrelatable parts displays provided a test of whether the completion effect might be based primarily on some process other than good form, such as the close proximity of rod segment edges (i.e., interpolation across a small spatial gap).

Method

Participants. The final sample consisted of 96 full-term infants (48 female; *M* age = 126 days, *SD* = 8.6), drawn from the same population of infants as described in Experiment 1. Nineteen additional infants were observed but not included in the sample due to excessive fussiness (18 infants) or interference from a sibling (1 infant). Participant recruitment procedures were the same as in Experiment 1.

Apparatus, stimuli, and procedure. The apparatus, stimuli, and procedure were the same as in Experiment 1, with the following exceptions. The infants were randomly assigned to either the small ring, small cross, control, half ring, relatable parts, or nonrelatable parts condition, 16 infants in each group. The objects and occluders were presented against a 12 × 20 grid of background dots measuring 32.0 × 23.5 cm (17.7 × 13.2°). The occluder in the noncontrol habituation displays measured 15.5 × 5.1 cm (8.8 × 2.9°). The ring measured 16.1 cm (9.1°) in diameter. As in Experiment 1, the tangents of the ring edges would meet at an angle of 162° behind the occluder. The cross measured 19.5 cm (11.0°) across, diagonally. The circle and cross in the habituation and test displays translated back and forth at the same rate, and through the same distance, as those in Experiment 1. The control habituation display consisted of a yellow face, 16.5 cm (9.4°) in diameter, translating back and forth through 38.2 cm (20.9°) at a rate of 9.6 cm/s (5.5°/s) in a looped animation. After habituation, the infants viewed the same test displays as those presented to the infants who were habituated to the small ring and small cross displays. Eight (of the 16) control group infants viewed the ring test displays first (six displays presented in alternation, three each of the broken and complete ring displays, 4 infants viewing the broken ring first and 4 the complete ring first), followed by the cross test displays. Eight of the control group infants received the opposite order (cross displays first, in alternation, followed by ring displays). Thus each control group infant viewed all test displays after habituating to the happy face.

The half ring habituation display consisted of only the right half of the small ring from Experiment 2. Posthabituation test displays consisted of a broken half ring, with a gap in the place occupied by the box in the habituation display, and a complete half ring, with no gap. The relatable parts habituation display consisted of a 6.5-cm (3.7°) rod part, oriented 42° counterclockwise, above the box and a 5.5-cm (3.1°) rod part, oriented vertically, below the box, arranged so that their edges were relatable. Posthabituation test displays consisted of a broken rod, with a gap in the place occupied by the box, and a complete (bent) rod. The nonrelatable parts habituation display consisted of two 6.5-cm rod parts, both oriented 42° counterclockwise, arranged so that their edges were neither relatable nor aligned. Posthabituation test displays consisted of a broken rod, with a gap in the place occupied by the box, and a complete rod, with the top and bottom rod parts joined by a third rod segment to form an object with two 96° angles. In all habituation and test displays, the visible rod parts underwent lateral translation at the same rate, and through the same distance, as the objects in Experiment 1.

Results and Discussion

As in Experiment 1, the data consisted of the mean of the two observers' judgments of the infants' looking times on each trial. Table 1 presents the nontransformed mean looking times on the last two habituation trials and on the six test trials, collapsed across trial block, for the small ring, small cross, control, half ring, relatable parts, and nonrelatable parts conditions. Infants who were habituated to the small ring and small cross displays exhibited posthabituation preferences for the broken objects, and recovered interest more to the broken objects than to the complete objects. In contrast, infants in the control group seemed to look about equally at the test displays. Infants who were habituated to the half ring display exhibited a posthabituation preference for the broken object, and appeared to recover interest in the broken object, but not in the complete object. Infants habituated to the relatable parts and nonrelatable parts displays showed a slight preference for the complete test display.

Data from the small ring and small cross conditions were first examined with a preliminary ANOVA including sex and order. There were no significant main effects or interactions involving these variables; therefore data were collapsed over sex and order for subsequent analyses. Data from the control condition were also examined with ANOVAs including sex, order (broken vs complete object first), and condition order (ring vs cross first) on looking times for the ring and cross test displays. Again, there were no significant effects or interactions, and data were collapsed across these variables in the analyses that follow. Finally, data from the half ring, relatable parts, and nonrelatable parts conditions were also examined with a preliminary ANOVA including sex and order. There were no significant main effects or interactions involving these variables; therefore data were collapsed over sex and order for subsequent analyses.

Small ring, small cross, and control conditions. The first analysis probed perception of object unity in the small ring and small cross conditions. Looking times during the six posthabituation test trials were examined with a 2 (condition: small ring vs small cross) × 2 (display) × 3 (trial block) mixed ANOVA. There was a significant effect of display, $F(1, 30) = 11.49$, $p = .0020$, resulting from greater looking overall at the broken test objects than at the complete objects. The effect of condition did not reach significance, $F(1, 30) = .44$, $p = .51$, nor did the effect of trial block, $F(2, 60) = .74$, $p = .48$, the Condition × Display interaction, $F(1, 30) = .05$, $p = .82$, the Condition × Trial Block interaction, $F(2, 60) = .06$, $p = .94$, the Display × Trial Block interaction, $F(2, 60) = .27$, $p = .77$, or the Condition × Display × Trial Block interaction, $F(2, 60) = 2.00$, $p = .14$.

Planned comparisons (Display × Trial Block ANOVAs) explored the preference for the broken objects, and changes in preference across trials, separately for the small ring and small cross conditions. For the small ring condition, there was a significant preference for the broken ring, $F(1, 15) = 6.40$, $p = .023$. The effect of trial block did not reach significance, $F(2, 30) = .16$, $p = .31$, nor did the Display × Trial Block interaction, $F(2, 30) = 1.38$, $p = .27$. For the small cross condition, there was a significant preference for the broken cross, $F(1, 15) = 5.37$, $p = .035$. The effect of trial block did not reach significance, $F(2, 30) = .88$, $p = .43$, nor did the Display × Trial Block interaction, $F(2, 30) = .64$, $p = .53$.

Infants' recovery of looking to each test display was explored via a 2 (condition: small ring vs small cross) × 3 (display: habituation, broken object, or complete object) ANOVA comparing the mean of the last habituation trial with the means of the three trials of each test display. There was a significant effect of display, $F(2, 60) = 12.94$, $p < .001$. The effect of condition was not significant, $F(1, 30) = .61$, $p = .44$, nor was the Condition × Display interaction, $F(2, 60) = 1.02$, $p = .36$. Post hoc tests (Tukey HSD) revealed significant recovery of interest both to the broken objects, $p < .001$, and to the complete objects, $p = .040$.

Planned comparisons (single-variable ANOVAs) explored recovery separately for the small ring and small cross conditions. For the small ring condition, there was a significant difference in looking times across the habituation and test trials, $F(2, 30) = 7.99$, $p = .0017$. Tukey HSD tests revealed significant recovery both to the broken ring, $p = .0013$, and to the complete ring, $p = .048$. For the small cross condition, there was a significant difference in looking times across habituation and test trials, $F(2, 30) = 5.44$, $p = .0096$. The infants recovered interest to the broken cross, $p = .0089$, but not to the complete cross, $p = .64$ (Tukey HSD).

Comparable analyses were conducted on data from the control group. A Display × Trial Block ANOVA on data from the small ring control condition yielded a significant effect of trial block, $F(2, 30) = 6.09$, $p = .0060$, the result of a decline in looking across trials. The effect of display failed to reach significance, $F(1, 15) = .38$, $p = .55$, as did the interaction, $F(2, 30) = 1.24$, $p = .30$. A Display × Trial Block ANOVA on data from the small cross control condition likewise revealed a significant effect of trial block, $F(2, 30) = 13.90$, $p < .001$. The effect of display failed to reach significance, $F(1, 15) = .16$, $p = .72$, as did the interaction, $F(2, 30) = 1.22$, $p = .31$. A single-variable ANOVA testing for recovery in the ring control condition yielded a significant difference in looking times across habituation and test trials, $F(2, 30) = 4.52$, $p = .019$. Tukey HSD tests revealed marginally significant decrement of interest to the broken ring, $p = .051$, and significant decrement of interest to the complete ring, $p = .028$. A single-variable ANOVA testing for recovery in the cross control condition yielded a marginally significant difference in looking times across habituation and test trials, $F(2, 30) = 2.55$, $p = .095$. Tukey HSD tests revealed nonsignificant decrement of interest both to the broken cross, $p = .11$, and to the complete cross, $p = .18$.

Comparisons of looking time data for infants who were habituated to the partly occluded objects vs those habituated to the happy face were conducted separately for the ring and cross conditions. A Condition (small ring vs small ring control) × Display × Trial Block ANOVA revealed significant effects of display, $F(1, 30) = 5.25$, $p = .029$, and trial block, $F(2, 60) = 3.53$, $p = .036$. The Condition × Display interaction was marginally significant, $F(1, 30) = 2.14$, $p = .15$. There were no other significant effects (condition $F(1, 30) = .08$, $p = .77$; Condition × Trial Block $F(2, 60) = 1.65$, $p = .20$; Display × Trial Block $F(2, 60) = 1.90$, $p = .16$; Condition × Display × Trial Block $F(2, 60) = .74$, $p = .48$). A Condition (small cross vs small cross control) × Display × Trial Block ANOVA likewise yielded significant effects of display, $F(1, 30) = 4.48$, $p = .043$, and trial block, $F(2, 60) = 10.08$, $p < .001$, and a marginally significant Condition × Trial Block interaction, $F(2, 60) = 3.13$, $p = .051$. Again, the Condition × Display interaction was marginally significant, $F(1, 30) = 2.89$, $p = .10$. There were no other significant effects (condition $F(1, 30) = .37$, $p = .54$; Display × Trial Block $F(2, 60) = 1.20$, $p = .31$; Condition × Display × Trial Block $F(2, 60) = .86$, $p = .43$).

Analyses of individual differences were computed on the data from Experiment 2 in the same manner as in Experiment 1. There were no significant differences in performance between fast and slow habituators, nor between infants classified as short or long lookers according to the criteria outlined in Experiment 1 (total time to habituate or peak habituation time). These analyses, therefore, suggest that even slow habituators were able to capitalize on the available global information to perceive object unity.

Comparisons to Experiment 1. An Experiment (large object vs small object) × Display × Trial Block ANOVA comparing infants' responses across Experiments 1 and 2 resulted in significant effects of display, $F(1, 62) = 20.40$, $p < .001$, and trial block, $F(2, 124) = 3.60$, $p = .030$. The Experiment × Display interaction failed to reach significance, $F(1, 62) = 1.57$, $p = .22$, as did the other effects (experiment $F(1, 62) = .73$, $p = .40$; Experiment × Trial Block $F(2, 124) = .70$, $p = .50$; Display × Trial Block $F(2, 124) = .34$, $p = .72$; Experiment × Display × Trial Block $F(2, 124) = .24$, $p = .78$). A Condition [large object (Experiment 1) vs small object control (Experiment 2, averaged across ring and cross displays)] × Display × Trial Block ANOVA again revealed significant effects of display, $F(1, 46) = 5.50$, $p = .023$, and trial block, $F(2, 92) = 9.34$, $p < .001$. The Condition × Display interaction did not reach significance, $F(1, 46) = 1.23$, $p = .23$, nor did the other effects (experiment $F(1, 46) = 1.82$, $p = .18$; Experiment × Trial Block $F(2, 92) = 1.07$, $p = .35$; Display × Trial Block $F(2, 92) = 1.13$, $p = .33$; Experiment × Display × Trial Block $F(2, 92) = .18$, $p = .84$). The lack of reliable differences in performance across Experiments 1 and 2 is not surprising: Although the infants in Experiment 1 preferred the broken object during test (proportion of looking at broken object = .53), their performance was not as robust as that of the infants in Experiment 2 who were habituated to the small objects (proportion of looking at the broken object = .60), and, indeed, did not reliably differ from that of the control group in Experiment 2 (proportion of looking at the broken object = .49; see Table 1). The weak pattern of performance in Experiment 1 is perhaps due to the fact that only a subset of the infants (short lookers) provided evidence of perception of object unity, as revealed by significant preference for the broken object test display.

Half ring, relatable parts, and nonrelatable parts conditions. Looking times during the six posthabituation test trials were examined with a 3 (condition: half ring, relatable parts, or nonrelatable parts) × 2 (display) × 3 (trial block) mixed ANOVA. The Condition × Display interaction was significant, $F(2, 45) = 6.95$, $p = .0023$. None of the other effects reached significance (condition $F(2, 45) = .08$, $p = .92$; display $F(1, 45) = 3.20$, $p = .08$; trial block $F(2, 90) = 1.04$, $p = .36$; Condition × Trial Block $F(4, 90) = .78$, $p = .54$; Display × Trial Block $F(2, 90) = .55$, $p = .58$; Condition × Display × Trial Block $F(4, 90) = 1.53$, $p = .20$).

Planned comparisons (Display × Trial Block ANOVAs) explored posthabituation preferences separately for the half ring, relatable parts, and nonrelatable parts conditions. For the half ring condition, there was a significant effect of display, $F(1, 15) = 29.50$, $p < .001$, and no other significant effects (trial block $F(2, 30) = .63$, $p = .54$; Display × Trial Block $F(2, 30) = .88$, $p = .42$). For the relatable parts condition, there was a significant Display × Trial Block interaction, $F(2, 30) = 3.60$, $p = .04$, and no other significant effects (display $F(1, 15) = .005$, $p = .95$; trial block $F(2, 30) = 1.14$, $p = .33$). For the nonrelatable parts condition, there were no significant effects (display $F(1, 15) = .52$, $p = .48$; trial block $F(2, 30) = 1.06$, $p = .36$; Display × Trial Block $F(2, 30) = .03$, $p = .97$).

Differences in recovery of interest between habituation and test trials, across the half ring, relatable parts, and nonrelatable parts conditions, were explored with a Condition × Display ANOVA. There was a significant effect of display, $F(2, 90) = 11.77$, $p < .001$. Tukey HSD tests revealed that across conditions, the infants recovered interest both to the broken object, $p < .001$, and to the complete object, $p = .001$. The Condition × Display interaction was marginally significant, $F(4, 90) = 1.99$, $p = .10$. The effect of condition was not significant, $F(2, 45) = .03$, $p = .97$. Recovery was explored separately for the three conditions with single-factor ANOVAs. For the half ring condition, there was a significant difference in looking time across the last habituation trial and the two test trials, $F(2, 30) = 10.61$, $p < .001$. Tukey HSD tests revealed significant recovery of interest to the broken object, $p < .001$, but not to the complete object, $p = .42$. For the relatable parts condition, likewise, there was a significant difference in looking across habituation and test trials, $F(2, 30) = 4.12$, $p = .03$. Tukey HSD tests revealed marginally significant recovery to the broken object, $p = .078$, and significant recovery to the complete object, $p = .03$. For the nonrelatable parts condition, the difference in looking across habituation and test trials was marginally significant, $F(2, 30) = 2.98$, $p = .067$. There was marginally significant recovery to the complete object, $p = .061$, but not to the broken object, $p = .23$.

To explore further the roles of proximity and good form in infants' perception of object unity, the data from the small ring and small cross conditions were compared to the half ring and nonrelatable parts conditions (i.e., isolated object segments), respectively. Data from the half ring and small ring conditions were entered into a Condition × Display × Trial Block ANOVA, which yielded significant effects of condition, $F(1, 30) = 5.82$, $p = .022$, the result of longer looking overall during test by infants habituated to the small ring, and of display, $F(1, 30) = 27.11$, $p < .001$, the result of longer looking at the broken object during test. The Condition × Display interaction was not significant, $F(1, 30) = 1.17$, $p = .29$, nor were the other effects (trial block $F(2, 60) = .31$, $p = .73$; Condition × Trial Block $F(2, 60) = .50$, $p = .61$; Display × Trial Block $F(2, 60) = 2.01$, $p = .14$; Condition × Display × Trial Block $F(2, 60) = .18$, $p = .84$). Data from the nonrelatable parts and small cross conditions were also examined with a Condition × Display × Trial Block ANOVA, which yielded a significant effect of condition, $F(1, 30) = 12.31$, $p = .0014$, resulting from longer looking overall during test by infants habituated to the small cross. There was also a significant Condition × Display interaction, $F(1, 30) = 4.81$, $p = .036$, resulting from differences in test display preference across experiments. Other effects did not reach significance (display $F(1, 30) = 1.46$, $p = .24$; trial block $F(2, 60) = 1.90$, $p = .16$; Condition × Trial Block $F(2, 60) = .02$, $p = .98$; Display × Trial Block $F(2, 60) = .32$, $p = .72$; Condition × Display × Trial Block $F(2, 60) = .10$, $p = .91$).

In summary, evidence was obtained in Experiment 2 for robust perception of object unity in displays containing good form: Infants habituated to a partly occluded ring or cross that were smaller than those employed in Experiment 1 looked longer at a broken object at test, relative to a complete object. Given that both test objects were consistent with the visible portions of the partly occluded object in the habituation display, this result implies that the infants exhibited a novelty preference and experienced the complete object as relatively familiar in comparison to the habituation display. This outcome cannot likely be attributed to an inherent preference for a broken ring or cross, because infants in the control condition, habituated to a stimulus unrelated to the habituation or test displays, exhibited no such preference. (It is unclear why the infants in the small ring condition recovered interest in the complete object, but this may be due to the fact that in all instances of the present design, infants are presented with two novel displays after habituation. Therefore some dishabituation to the complete object is not unexpected. See Bornstein, 1985, for discussion.)

Infants in the half ring condition also provided evidence of perception of object unity. In contrast, infants who were presented with the relatable parts and nonrelatable parts displays did not perceive unity. These findings appear to indicate that the relatively close proximity of the ends of the visible parts of the occluded objects did not, in and of itself, provide sufficient information in support of unit formation. Rather, good form seemed to be a more potent source of information for unity. It seems likely that curvature per se, and not only the global circular shape available only in the ring displays, supports perception of unity. This outcome contrasts with the looking patterns exhibited by infants who viewed the relatable parts and nonrelatable parts displays, who showed no consistent test display preference. The relatable parts display was similar to the half ring in that the edges of the visible rod parts were relatable across a narrow gap. In the absence of curvature, however, perception of unity was not obtained. Infants in both the relatable parts and nonrelatable parts conditions exhibited a tendency toward recovery to the complete objects during test, which provides corroborative evidence for the suggestion that misaligned edges specify disjoint objects to young infants (cf. Johnson & Aslin, 1996; Smith, Johnson, & Spelke, 2000).

GENERAL DISCUSSION

The present studies provide evidence that young infants detect and utilize a combination of motion and good form to perceive the unity and coherence of partly occluded objects. After viewing displays in which a moving large ring or large cross was partially hidden, fast habituators (defined as those infants who habituated in the minimum number of trials) looked reliably longer at a broken object, relative to a complete object. Slow habituators, in contrast, did not appear to perceive object unity: There was no reliable posthabituation preference among infants who habituated in more than the minimum number of trials. In the second experiment, infants appeared to perceive object unity in moving, partly occluded small ring and small cross displays, indicating improved performance when the objects were reduced in size. There were no reliable differences in performance as a function of habituation times. Results of the second experiment also indicated that good form, rather than proximity, supported perception of object unity: In displays in which two moving rod parts were relatively close across a small occluder, perception of unity did not obtain unless the rod parts’ edges lay on a curved shape. Infants who were habituated to a display in which rod parts were neither relatable nor aligned provided some evidence for perception of disjoint objects. Together with the findings of Johnson and Aslin (1995, 1996), the present results suggest that young infants perceive partly occluded object displays in accord with a range of Gestalt principles: good form (both curvature and global configuration) and good continuation, which are both stationary configurational information sources, in addition to common motion.

Gestalt information, then, appears to be operational in young infants' object perception, but sensitivity to this information (and other stationary configurational information) may be fragile in its initial ontogenetic forms. On the basis of some negative findings concerning young infants' utilization of the range of Gestalt information, Spelke and Van de Walle (1993) concluded that early object perception instead is guided by a set of core principles (cohesion, contact, and continuity). Development, according to this account, consists of elaborations on this unified conceptual system, by the acquisition of knowledge of the typical appearances and behavior of specific types of objects. This enrichment process occurs over the first postnatal months. For example, infant sensitivity to Gestalt information emerges after a period of exposure to objects of particular kinds: Once infants recognize familiar classes of objects, surface segregation and unit formation may begin to accord with Gestalt information because most objects are smooth and regular, properties that may contribute to increasing effectiveness at parsing the visual array (Spelke, 1990; Spelke, Breinlinger, Jacobson, & Phillips, 1993). Intriguing support for this notion is found in recent research with adults demonstrating that object recognition precedes figure–ground perception (Peterson, 1994).

A contrasting perspective is provided by Needham (1997; Needham et al., 1997). The development of veridical surface segregation, according to this view, involves both the acquisition of knowledge of object properties (including physical properties, such as solidity and support) and the integration of various sources of visual information, to arrive at an interpretation of a particular display. Improvements in information-processing skills are central to this account: Surface segregation may be challenged by limitations in encoding, comparison, and interpreting available visual information. A secondary consideration is the possibility of a hierarchy of visual information, such that some sources may be subordinate to others. For example, information sources with high ecological validity, such as spatial and kinetic information, may dominate early object perception because they are thought to provide the most reliable indications of object boundaries (Needham & Kaufman, 1997; cf. Jusczyk, Johnson, Spelke, & Kennedy, 1999; Kellman, 1996).

A similar account, though more perceptual than cognitive, is rooted in the Johnson and Aslin (1996) threshold model. According to this view, veridical surface segregation relies on several subskills, such as the placement of constituent surfaces into the appropriate depth planes, the assignment of visible boundaries to the appropriate surfaces, and the joining of visible boundaries to those that are not directly visible, but continue behind an occluder (Nakayama & Shimojo, 1990). If insufficient information is available, or if the observer is insensitive to the available information (as may be the case with very young infants), surface segregation and unit formation are precluded. Surface perception is opportunistic in its functioning, taking advantage of whatever information might be accessible to accomplish the task (Ramachandran, 1988). There is no privileged information source, according to the threshold model, and the model is mute with respect to ecological validity, considering it an empirical (and still open) question. Recent evidence has begun to dispute, for example, the primacy of motion in infants' object perception: It appears that edge alignment is also a potent source of information for unit formation, for both infants (Experiment 3 of the present study; Johnson & Aslin, 1996; Smith et al., 1999) and adults (Johnson & Aslin, 1996; Jusczyk et al., 1999). There are, at present, inadequate data upon which to build a detailed characterization of mechanisms of development of unit formation, but speculation has centered on improvements over the first few postnatal months in the tuning and coordination of cortical assemblies in the visual system, which must act in concert to bind visible surface features into veridical percepts. These improvements are at least partly a function of visual experience (Johnson, 2000).

Finally, consider the position of the Gestalt psychologists concerning young infants' object perception. Though a purely nativist view was rejected (Koffka, 1935; Köhler, 1947), dynamic forces were thought to organize activity across the life span, and a "primitive mentality" was ascribed to the human neonate (Koffka, 1928/1959). This was evident, for example, in neonates' ability to distinguish figure from ground, and in their responses to relatively complex stimuli (such as the human face and voice), suggesting that the infant's perceptual experience is never one of disorganized chaos. The development of object perception was thought to follow the acquisition of the "meanings" of specific objects, which enriched existing structure with respect to perceptual organization. Mechanisms of development were proposed to involve active exploration, which imparts additional information about specific object kinds (Koffka, 1928/1959). This view differs from the Spelke (1990) account in that the roles of perception and experience with objects are reversed: According to the Gestalt view, perceptual organization precedes object knowledge; according to the Spelke view, object knowledge contributes to perceptual organization.

The results of the present study can help clarify the utility of these approaches concerning the development of object perception. It seems likely that protracted experience viewing, manipulating, or recognizing objects is not necessary to respond to Gestalt information, given that sensitivity to common motion, good form, and good continuation is present by 4 months of age. Such findings appear to obviate accounts of infant perception based on recognition of specific object kinds. However, these findings are consistent with the Needham, Johnson, and Gestalt accounts, all of which have provided less specific predictions regarding details of infants' object perception. Both the "top-down" (Needham, 1997) and "bottom-up" (Johnson, 1997) views appear to characterize a portion of the extant research on the development of sensitivity to Gestalt information, but research with younger infants is necessary to provide a more complete description of these processes.

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