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Young Infants' Perception of Object Unity in Two-Dimensional Displays

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Two-dimensional displays were used to investigate the perception of object unity in 48 2-month-old and 48 4-month-old infants. The infants were habituated to a computer-generated display depicting a rod in motion behind a box. Posthabituation test trials consisted of two rod pieces (broken rod) and a complete rod, presented three times each in alternation. The 4-month-olds looked longer at the broken rod than at the complete rod, suggesting that the hidden unity of the rod behind the box was inferred. This finding replicates results with real-object displays and indicates that computer-generated displays may be successfully employed to study questions of object unity in infants. The 2-month-olds looked equally at both test displays. Two months of age may represent a transitional period, from responding to what is directly visible in a visual display to inferring the existence of the occluded portions of objects. Alternatively, infants at this young age may not be sensitive to the visual information that specifies object unity in the displays.

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two-dimensional displays depth perception

Piaget (1952, 1954) posited that infants do not conceptualize an object's continued existence at a particular location, after occlusion and displacement, until 18 to 24 months of age. Recent studies indicate that awareness of such object properties as spatiotemporal continuity, cohesiveness, and boundedness is often demonstrated much earlier in development. For example, Kellman and Spelke (1983), Kellman, Spelke, and Short (1986), and Slater, Morison, et al. (1990) have found evidence of 4-month-olds' perception of the unity (connectedness) of objects that are partially occluded.

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Typically in these more recent studies, an infant is first shown a moving object (e.g., a rod) whose center portion is occluded by another object (e.g., a box), until habituation of looking occurs. The infant then views test displays consisting of a complete rod or two rod pieces with a visible gap corresponding to the location of the box in the habituation displays (broken rod). Infant dishabituation can be used as an index of the test stimuli's perceived novelty, in comparison to the familiar habituation stimulus (Olson, 1976). In the Kellman and Spelke (1983) paradigm, attending more to the broken rod than to the complete rod indicates that the infant experienced the broken rod as relatively novel. In this case, the complete rod is inferred to be relatively familiar (i.e., the visible portions of the rod in the habituation display were perceived as connected behind the box, although the connectedness was not seen directly).

Kellman and Spelke's (1983) 4-month-olds appeared to perceive the rod as continuous behind the box when the visible portions of the rod moved concurrently while the box remained stationary. Even when two dissimilar surfaces (i.e., a rod piece aligned with an irregularly shaped object) moved concurrently, the infants seemed to perceive them as forming a continuous surface behind the box. Vertical motion of the partially occluded rod, and motion in depth, also supported perception of object unity in 4-month-olds (Kellman et al., 1986). However, when the display was stationary, or when the box moved together with the visible rod pieces, the infants apparently did not perceive the rod as continuous behind the box. Thus, concurrent motion of visible surfaces, relative to an occluder, appears to play a key role in young infants' perception of object unity.

Slater, Morison, et al. (1990) reported another instance in which infants apparently did not perceive object unity in rod-and-box displays. In their study, neonates consistently preferred to look at the complete rod versus the broken rod after habituation. This indicates that neonates may not perceive object unity under these conditions (Slater, Johnson, Kellman, & Spelke, 1994). One issue of interest in this study involves gaining a better understanding of the development of perception of object unity from birth to 4 months of age. This is addressed in Experiment 2. A second issue concerns whether nonmotion-carried visual information, such as depth cues, is necessary to support infants' perception of object unity. This is addressed in Experiment 1 with reduced-cue, two-dimensional displays.

EXPERIMENT 1

Although much is known about the types of motion that support perception of object unity (Kellman & Spelke, 1983; Kellman et al., 1986), the relation between depth cues and 4-month-olds' perception of object unity in moving displays has heretofore remained unexplored. It seems likely that veridical perception of depth placement of surfaces in the displays is necessary (but not sufficient) for perception of the unity of partially occluded surfaces.

Two possible candidates for these depth cues might be motion parallax and binocular disparity, important in specifying object boundaries and the layout of objects in the environment (Gibson, 1979). It is unclear, however, whether these depth cues function in 4-month-olds' perception of object unity.

Four-month-olds have been found to use motion parallax as information for the perception of object boundaries (Kellman, Gleitman, & Spelke, 1987; Kestenbaum, Termine, & Spelke, 1987) and object form (Kellman & Short, 1987). However, Kellman et al. (1987) found that motion parallax was not useful in 4-month-olds' perception of object unity in stationary displays.

Although 4 to 5 months of age seems likely to be the time of onset for sensitivity to binocular disparity (Birch, Gwiazda, & Held, 1982, 1983; Fox, Aslin, Shea, & Dumais, 1980), this depth cue also may be unnecessary for the perception of object unity. This is because Kellman and Spelke's (1983) 4-month-olds apparently did not perceive the unity of the visible portions of the rod that did not move independently of the box, even though binocular disparity specifying rod–box separation was available in these displays.

For these reasons, the use of computer-generated displays seems well suited to study questions of infants' perception of object unity. Two-dimensional displays lack motion parallax and binocular disparity as information for surface segregation, but because these depth cues are probably not essential to infants' perception of object unity, it may be possible to employ computers to conduct further research in this area with better control of spatial-temporal stimulus properties.

In considering two-dimensional displays such as motion pictures, Gibson (1979) noted that such displays are "thoroughly saturated with meaning" (p. 293) via their depiction of the changing optic flow. Objects and events can be rendered with "the utmost precision and elaboration" (p. 293). Computer-generated displays present the researcher with certain advantages over real-object displays, such as precise control over stimulus characteristics, including the development of displays that could not be fashioned otherwise. However, there may be a fundamental problem with the use of computer-generated displays in object unity research. That is, two-dimensional displays present a "cue-conflict" situation. On the one hand, there is information on a flat screen for coplanarity of visible surfaces. This would of course preclude the possibility of the hidden connectedness of one surface to another. On the other hand, some information for the unity of two surfaces (e.g., common motion) is retained.

Thus, it seemed advantageous to investigate 4-month-olds' perception of object unity in computer-generated, two-dimensional displays. Although the stimuli were all located in the same plane, the rod-and-box displays in this study resembled those employed by Kellman and Spelke (1983) in terms of visual angle, surface motion, and so forth.

If 4-month-olds experience a cue-conflict as outlined above, they might not be expected to perceive the visible surfaces of the rod as connected behind the box. However, if any cue-conflict has been overcome by 4 months of age (or is not a factor in infants' responses to two-dimensional displays), then the infants should show results similar to those observed by Kellman and Spelke (1983).

Method

Subjects

Forty-eight infants comprised the final sample (M age = 122 days, range = 109–152 days). An additional 6 infants were observed but not included in the sample due to fussiness (5) or low interrater agreement (1) (Pearson $r < .70$). The infants were the children of parents participating in childbirth classes at three suburban hospitals. The majority of the infants were from Caucasian, middle-class families.

Design

There were 16 infants in each of three conditions: experimental, control, and lag. Infants in the experimental and lag groups were habituated to a computer-generated rod-and-box display, with the top and bottom portions of the rod undergoing concurrent lateral motion behind the box. Infants in the control group were habituated to a similar rod-and-box display, but the bottom portion of the rod remained stationary, while the top portion of the rod moved laterally.

Infants in the lag group received two extra trials with the habituation stimulus before viewing the test displays. This group was incorporated as a control for spontaneous regression (Bertenthal, Haith, & Campos, 1983). Spontaneous regression refers to fluctuations in looking time patterns due more to chance than a change in interest to a particular display, a possibility not controlled for in previous object unity studies. Estimates of spontaneous regression can be partialled out of the experimental group's data, depending on the lag group's results.

Infants in all three groups viewed the same two test displays, consisting of a broken rod and a complete rod in alternation, for three trials each, with counterbalancing of the initial test display.

Apparatus and Stimuli

A Zenith 386 CPU, with a 76-cm NEC color monitor, was used to generate the displays. The infant and monitor screens were located inside an enclosure, 2 m square, covered in black cloth. Two observers viewed the infant through small peepholes cut into either side of the enclosure.

The computer presented stimulus displays, stored each subject'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 two hand-held microswitches, interfaced with the computer's game port.

One observer was knowledgeable about the displays and experimental design. However, this observer was blind to the experimental condition of any individual participant and to the particular stimulus being presented on the screen at any given time. The second observer was not allowed to view the displays at any time and was naive to the hypotheses and the experimental design.

The habituation stimulus consisted of a computer-generated 16-cm × 8-cm blue box, subtending 15.0° × 7.5° visual angle. The box was oriented with its long axis horizontal. A yellow rod, 24 cm in length, subtending 22° visual angle and oriented 35° counterclockwise from the vertical, underwent lateral translation at a rate of 5 cm/s (4.8°/s) behind the box. In the control condition, only the top visible portion of the rod moved; the bottom remained stationary. The background consisted of a 24 × 32 grid of regularly spaced white dots (texture elements) against a black field. Background texture was deleted at the leading edge of the rod and accreted at the trailing edge of the rod, as the rod moved across the screen. With the exception of one person, the infants' parents (N = approximately 120) unanimously reported that the rod-and-box display appeared to contain a complete, continuous object (the rod) partially occluded by another object (the box).

The two test stimuli (broken and complete rods) were similar to the rod portion of the habituation stimulus, but without the box. The broken rod contained an 8-cm gap in its center, with background texture visible in the gap. In the complete-rod display, the gap was filled in, forming a continuous rod. Both complete and broken rods moved in the same translatory motion as the visible portions of the rod in the habituation display.

Procedure

The infants were placed in an infant seat and positioned with their face approximately 60 cm from the center of the monitor. The rod-and-box display was presented until the habituation criterion was met. This criterion was defined according to a common infant-control procedure (Horowitz, Paden, Bhana, & Self, 1972) as a decline in looking times during three consecutive trials, adding up to less than half the total looking times during the first three trials. If the total of the looking times during the first three trials was less than 12 s, the criterion was based on the first three subsequent trials for which looking time totaled 12 s or more.

Timing of each trial began when the infant focused visual attention on the screen after display onset. Each observer independently indicated how long the infant looked at the display by pressing a separate microswitch for as long as the infant maintained gaze on the screen. Each observer released the microswitch when the infant was judged to have looked away from the screen. An individual trial was terminated when both observers released their microswitches for 2 overlapping s. At this point, the screen was turned off automatically 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 (lag infants received two additional trials with the habituation stimulus before viewing the test displays). The test displays were seen three times each, in alternation, for a total of six posthabituation trials. Half the infants in each group viewed the broken rod first after habituation, and half viewed the complete rod first. The order for assignment to the resulting six cells was controlled by the computer according to a random schedule, until all cells were filled.

Results and Discussion

Each infant contributed six posthabituation looking times to the analyses, three for the broken rod and three for the complete rod. (Four infants, 1 in the experimental group, 1 in the lag group, and 2 in the control group, viewed only one or two pairs of test displays due to fussiness.) Looking times were calculated by averaging the two observers' judgments for each test trial. Interobserver agreement was high for the infants included in the analyses (Pearson *r*s averaged .97, range = .84–.99). There were no significant effects of order of test display presentation in preliminary analyses. Thus, data were pooled over this variable in the analyses reported below.

Occasionally there were looking times that seemed unusually long, perhaps due to so-called "obligatory attention" rather than interest on the infant's part (Johnson, 1990). These scores did not seem representative of "true" interest in the displays. Each outlier (a score that exceeded 3 *SD*s from the mean for its cell) was replaced by the cell mean. There were few outliers, accounting for 2.5% of the 278 total observations. (The analyses reported below were repeated including outliers. Outcomes were essentially the same in all cases.)

The 4-month-olds' data closely conformed to the results reported by Kellman and Spelke (1983) and Slater, Morison et al. (1990). Figure 1 reveals that the infants in the experimental and lag groups looked more at the broken-rod than at the complete-rod test displays, whereas infants in the control group looked about equally at the two displays.

Prior to the overall analysis of looking times, the possibility of spontaneous regression in the lag group's data was examined. The response patterns of the lag group revealed no spontaneous regression of looking times (i.e., no spontaneous "recovery" of interest) during the two lag trials (Figure 1B). The average looking times during the two lag trials did not differ from the last two habituation looking times, $t(15) = 0.76$.

However, the possibility remained that the dishabituation patterns of the experimental and lag groups might differ in some way due to the extra exposure of the lag infants to the rod-and-box display. The two groups' looking times were compared with a 2 (group: experimental vs. lag) × 2 (display: broken rod vs. complete rod) × 3 (trial: first, second, or third block of trials) MANOVA, with repeated measures on the last two factors. There was a significant effect of display, $F(1,28) = 16.42$, $p < .001$, resulting from greater looking at the broken rod ($M = 16.16$ s, $SD = 20.92$) than at the complete rod ($M = 7.71$ s, $SD = 7.44$). There was also a significant effect of trial, $F(2,58) = 5.31$, $p < .01$, resulting from an overall decline in looking across test trials. There were no other significant effects or interactions. Thus, there were no differences (e.g., due to spontaneous regression) between the experimental and lag groups in their responses to the test displays, and it was not necessary to apply Bertenthal et al.'s (1983) method for partialling out estimates of spontaneous regression in the experimental group's data.

Given the similarity in responding, the experimental and lag groups' data were pooled in order to compare the looking times of the combined group with those of the control group. A 2 (group: combined vs. control) × 2 (display: broken rod vs. complete rod) × 3 (trial: first, second, or third block of trials) repeated-measures MANOVA yielded a significant main effect of display, $F(1,42) = 7.26$, $p = .01$, due to greater overall looking at the broken rod than at the complete rod. There was also a significant interaction between group and display, $F(1,42) = 6.55$, $p < .05$. This interaction was due to greater looking at the broken rod by the combined group ($M = 16.16$ s, $SD = 20.92$) than by the control group ($M = 8.03$ s, $SD = 6.86$), $F(1,42) = 4.00$, $p = .05$.

In sum, the experimental and lag groups showed a preference for the broken rod over the complete rod. This preference for the broken rod was greater than that demonstrated by infants in the control group, who did not show evidence of preferring either test display. These results replicate those obtained with real-object displays (i.e., Kellman & Spelke, 1983; Slater, Morison, et al., 1990) and indicate that it may be appropriate to use computer-generated displays to conduct further object unity research.

EXPERIMENT 2

Kellman and Spelke (1983) claimed that perception of partly occluded objects is rooted in

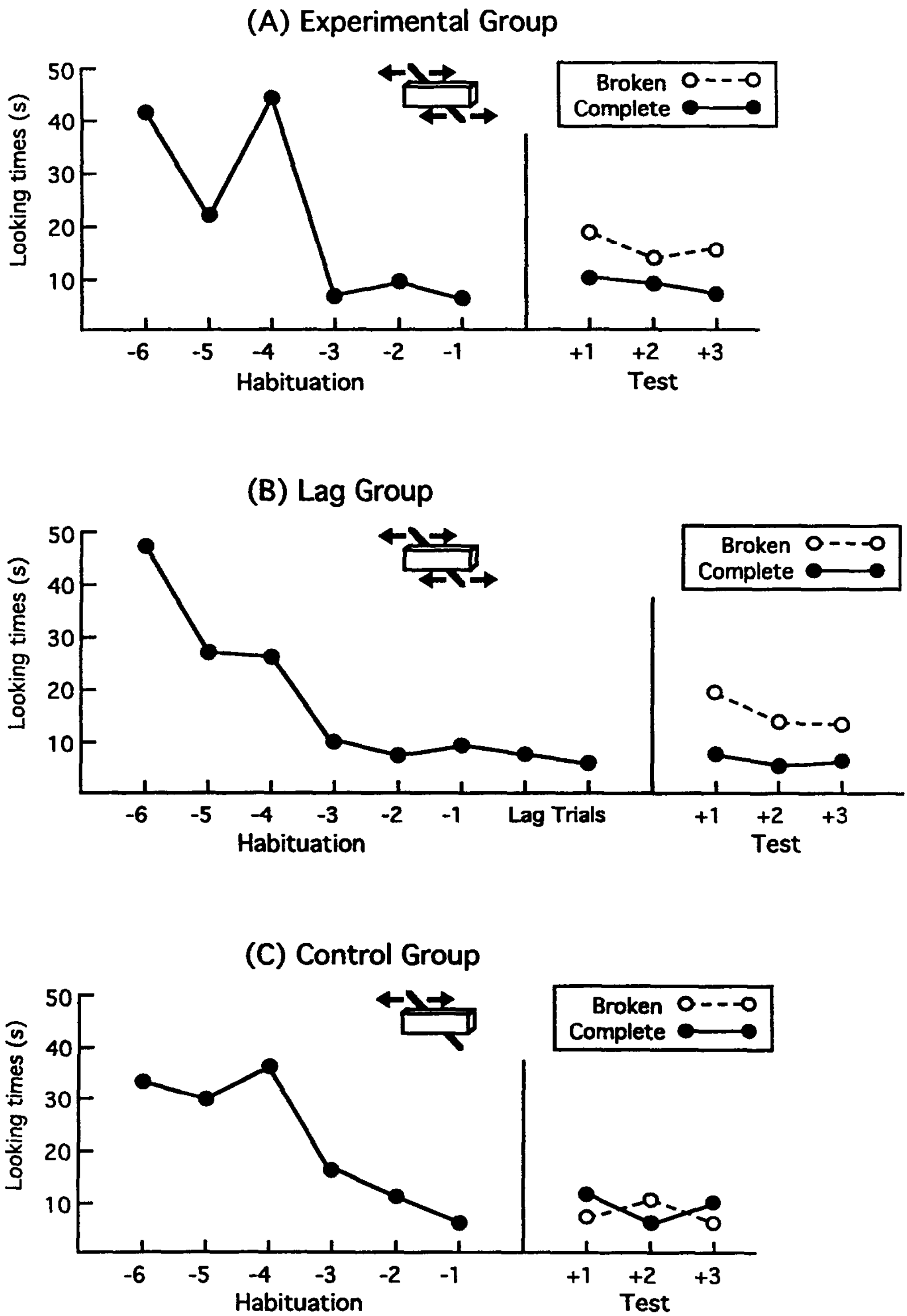

Figure 1. Mean looking times by 4-month-olds in (A) the experimental group, (B) the lag group, and (C) the control group.

an unlearned conception of the world (Spelke, 1985, 1988). In their view, humans may begin life with a tendency to experience objects as coherent, independent, and persisting over time.

It is possible, however, that perception of object unity develops over the first few months of life as the infant acquires experience with objects in the daily environment and gains sensitivity to optical information specific to object properties. Slater, Morison, et al. (1990) and Slater et al. (1994) reported evidence from neonates suggesting that this may be the case. In contrast to 4-month-olds, Slater et al.'s neonates preferred the complete rod over the broken rod. Slater, Morison, et al. (1990) concluded that neonates do not perceive the parts of a partially occluded object undergoing concurrent motion as connected behind an occluder. These results, and those of Kellman and Spelke (1983), suggest that perception of object unity develops between birth and 4 months of age.

For this reason, 2-month-olds were presented with rod-and-box, broken-rod, and complete-rod displays in this second experiment. If the 2-month-olds show a systematic preference for the broken rod (after habituation to the rod-and-box display), this would indicate that the onset of perception of object unity may occur sometime between birth and 2 months of age. A preference for the complete rod would provide evidence against early perception of object unity.

Method

Subjects

The subjects were 48 2-month-olds (M age = 61 days, range = 51–71 days) recruited from the same pool as the 4-month-olds in Experiment 1. An additional 8 infants were observed but not included in the sample due to fussiness (5), sleepiness (2), or low interrater agreement (1) (Pearson $r < .70$). Overall, interrater agreement (Pearson r) ranged from .81 to .99, averaging .96.

Two infants in the experimental group and two in the lag group viewed only one or two pairs of the test displays due to fussiness. Outliers (scores exceeding 3 *SD*s from the cell mean) were replaced, as in Experiment 1. Once again, outliers accounted for only 2.5% of the 278 observations, and inclusion of outliers did not affect subsequent interpretation of the analyses.

The design, apparatus, stimuli, and procedure of Experiment 2 were the same as those of Experiment 1.

Results and Discussion

The same series of analyses was performed on looking times from Experiment 2 as in Experiment 1. In contrast to the 4-month-olds in Experiment 1, the 2-month-olds in the experimental and lag groups did not exhibit a significant preference for either of the test displays (see Figure 2).

Like the 4-month-old lag group infants, the response patterns of the 2-month-olds in the lag group showed no evidence of spontaneous regression (Figure 2B). There was no significant difference between looking times on the two lag trials and the last two habituation trials. A 2 (group) $\times$ 2 (display) $\times$ 3 (trial) MANOVA revealed no significant differences in dishabituation patterns between the experimental and lag groups. When the experimental and lag groups' data were combined and compared to the control group with a group $\times$ display $\times$ trial MANOVA, no significant main effects or interactions were revealed.

In sum, there was no consistent pattern of results in the 2-month-olds' data. However, the 2-month-olds' data were further examined by looking for possible systematic differences between those infants in the experimental and lag groups who preferred the broken rod after habituation, like the 4-month-olds, and those who preferred the complete rod, like neonates (Slater, Morison, et al., 1990; Slater et al., 1994). Three possible sources for a between-subject difference in preference patterns were examined.

First, although the infants were relatively homogeneous in terms of age, as calculated from date of birth (51–71 days), there was a wider range in terms of age as calculated from due date (43–87 days). It might be that infants who showed the more mature response were older in terms of gestational age (Kellman & von Hofsten, 1992).

A second analysis examined whether the preference patterns were correlated with differences in time to habituate (range = 77.78 s–1063.52 s). Infants who habituate quickly tend to be faster processors of information (Colombo, Mitchell, Coldren, & Freeseman, 1991) and demonstrate better performance on subsequent measures of intelligence (McCall & Carriger, 1993; Rose, Feldman, & Wallace, 1988) than infants who take longer to habituate.

Third, the infant's sex may play a role in determining the patterns of preference for one display relative to the other. There is some evidence (Baillargeon & DeVos, 1991; Gwiazda, Bauer, & Held, 1989) suggesting that females may possess an advantage over males in terms of visual and cognitive development during early infancy.

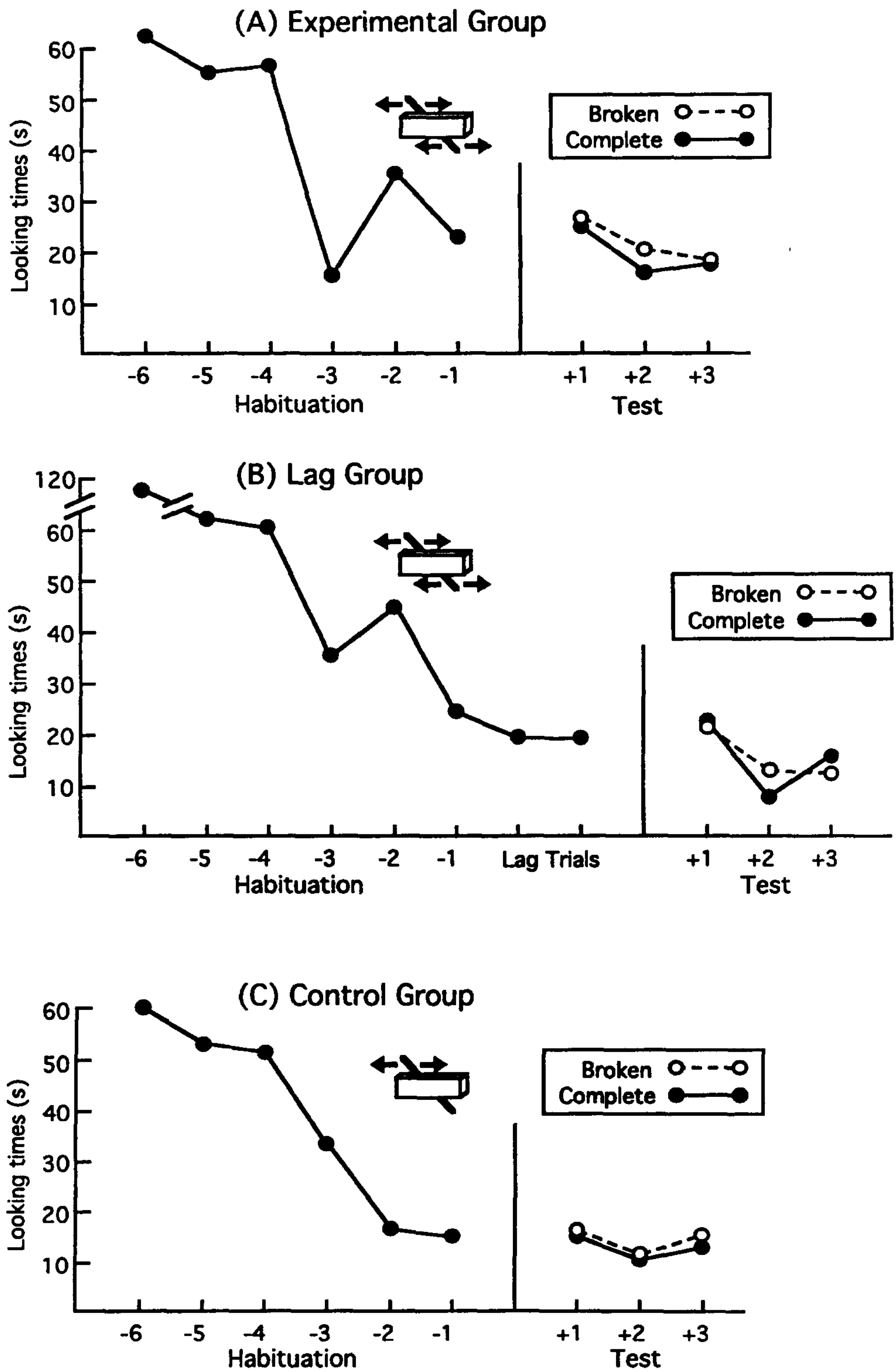

Figure 2. Mean looking times by 2-month-olds in (A) the experimental group, (B) the lag group, and (C) the control group.

Looking times of the experimental and lag groups were converted to preference scores (a preference score greater than .50 indicates preference for the broken rod) to examine whether preferences for the broken rod were related to one or more of the factors described above. Regression equations were computed on the relation between gestational age in days (M = 57.69 days, SD = 8.44) and preference for the broken rod (M = .51, SD = .22). The relation between total time to habituation (M = 335.56 s, SD = 251.87) and preference was examined in the same manner. Neither of these analyses yielded significant effects.

A one-way ANOVA, with sex as the independent variable and preference as the dependent variable, was also conducted. The results revealed no effect of sex for this sample, consisting of 15 males and 17 females (M preference for the broken rod = .56 and .47, respectively).

The results of Experiment 2 do not support firm conclusions regarding the perception of object unity in 2-month-olds. Unlike neonates or 4-month-olds, the 2-month-olds' preference for one test display relative to the other was approximately equal in this study. It may be that these infants did not form a clear impression of the rod-and-box display. That is, the rod pieces were not perceived by the majority of infants as connected, nor were they necessarily perceived as disjoint objects. (It is unclear why there was *no* dishabituation to either test display. *Both* test displays were somewhat novel compared to the rod-and-box display.)

Two months of age, therefore, may represent a transitional period, from responding to what is directly visible in a visual display to inferring the existence of the occluded portions of objects (or the connectedness of visible parts). Alternatively, infants younger than 4 months may not be sensitive to the visual information in the displays that specifies object unity. These interpretations are considered in detail below.

GENERAL DISCUSSION

Computer-generated displays have been employed in previous research to explore several aspects of visual perception in infants. Examples include studies of infants' perception of biomechanical motion (Bertenthal, Proffitt, & Kramer, 1987; Bertenthal, Proffitt, Spetner, & Thomas, 1985) and infants' perception of depth from boundary flow (Craton & Yonas, 1988), accretion and deletion of texture (Granrud et al., 1984), and interposition (Granrud & Yonas, 1984).

In Experiment 1, 4-month-olds appeared to perceive object unity in computer-generated displays, which did not contain three-dimensional depth cues. Although motion parallax and binocular disparity undoubtedly play a role in 4-month-olds' perception of the layout of objects in their surroundings, such information does not seem to be necessary for perception of object unity by 4-month-olds.

What, then, is the salient visual information that contributes to infants' perception of object unity? Clearly, the separation of display elements must be discerned in order to perceive object unity. The apparent separation of the rod, box, and background was specified by several depth cues. These included interposition of the box in front of the rod, accretion and deletion of background texture by the moving rod, motion of the rod relative to the box and the background, and concurrent motion and alignment of the visible portions of the rod. These cues are not completely independent, and it may be that the infants did not attend to one cue excluding all the others (Yonas & Granrud, 1985).

However, there is evidence that suggests that some of these cues may not function in depth perception before 4 months of age. For example, 4-month-olds may not be sensitive to interposition as a cue for relative depth. Seven-month-olds, but not 5-month-olds, were found to reach more often toward part of a two-dimensional display that appeared closer to the viewer, as specified by interposition of the display's parts (Granrud & Yonas, 1984).

Accretion and deletion of texture appears to play a role in depth perception by 5 months of age. Infants in this age group reached more often toward the apparently closer part of a two-dimensional display in which the only depth cue was accretion and deletion of texture at the edges of the "near" surface (Granrud et al., 1984). Whether 4-month-olds would perform similarly is unknown, given that Granrud et al. (1984) did not test infants younger than 5 months of age.[1] By 3 months of age, infants appear to abstract the shape of two-dimensional

[1] Johnson, Aslin, & Náñez (1994) recently obtained evidence that 4-month-olds' perception of object unity in two-dimensional displays is severely attenuated in the absence of background texture.

objects from interposition and accretion and deletion of texture (Kaufman-Hayoz, Kaufman, & Stucki, 1986), but it is unknown at this time whether depth order in displays is also perceived from this information.

It may be, however, that concurrent motion and relative motion are important in the perception of object unity in 4-month-olds. Kellman and Spelke (1983) found that in the absence of concurrent motion of the rod pieces relative to the box, the connectedness of the rod was apparently not perceived. It also may be that alignment of the visible parts of a partially occluded object facilitates perception of the separation of this object from the occluder (Kellman & Spelke, 1983; Kellman & Shipley, 1991). However, the relevant studies to test effects of misaligned surfaces on perception of object unity have not yet been reported in the literature.[2]

Thus, at this time, the bulk of the available evidence would suggest that concurrent motion and relative motion (and perhaps alignment) of visible elements behind the occluder constitute the information most likely contributing to 4-month-olds' perception of object unity. It remains to be determined through future research which, if any, of these cues is most salient, or whether some combination of cues is required.

Four-month-olds' perception of the unity of partially occluded, moving surfaces seems rather robust, occurring even under reduced-cue conditions such as those in Experiment 1. However, the 2-month-olds in Experiment 2 did not exhibit a consistent pattern of responses. There are several possible interpretations of this result.

In order to perceive the unity of two surfaces in a display, there are several necessary (but not individually sufficient) abilities. First, a minimal level of visual resolution is necessary in order to distinguish the display elements and their motions. Second, as noted above, the visual information relevant to object unity must be attended to (e.g., depth placement, common motion of the rod pieces). If the display is two-dimensional, the cue-conflict (between information for coplanarity and information for surface segregation) must be resolved in favor of segregation. Finally, it may be that inferential ability, a cognitive skill, also plays a role in perception of object unity. Limitations in any one of these abilities could undermine young infants' expression of perception of object unity.

The first of these limitations, as explanations for the 2-month-olds' response pattern in Experiment 2, can be ruled out. For example, it is unlikely that poor visual acuity prevented the infants from distinguishing the displays from each other (Aslin, 1987). The neonates in Slater, Morison, et al. (1990) and Slater et al. (1994) exhibited a consistent preference for the complete rod over the broken rod, and neonates have poorer visual acuity than 2-month-olds.

Although Slater, Morison, et al.'s (1990) results from neonates suggest that they have visual acuity sufficient for distinguishing between the habituation display and the two test displays, it may have been that the neonates in this study did not perceive the spatial (depth) separation of the rod and box in the habituation display. If the rod pieces were viewed as occupying the same plane as the box, it is not surprising that the unity of the rod was not perceived. That is, they would not be expected to "fill in" the missing part of the rod, because there was no gap to fill in (Slater, 1995).

This possibility was addressed in a recent study of neonates' perception of object unity (Slater et al., 1994) in which the separation of the rod and box was increased relative to Slater, Morison, et al.'s (1990) original display. The distance between the rod and box was known from previous research to be detectable by neonates (Slater, Mattock, & Brown, 1990). Even with this increased depth placement, however, the neonates preferred the complete rod after habituation and, thus, did not appear to perceive the unity of the rod pieces.

It also seems unlikely that difficulty with the cue-conflict inherent in two-dimensional displays contributed to the 2-month-olds' response pattern. Even when 2-month-olds are presented with real, three-dimensional rod-and-box displays (thus removing any cue-conflict), they exhibit no consistent posthabituation preference for either the broken or the complete rod (Johnson, Slater, & Aslin, 1994).

It may have been that the 2-month-olds (and the neonates in Slater et al., 1994, and Slater, Morison, et al., 1990) did not attend to the visu-

[2] Johnson, Aslin, & Náñez (1994) recently found that 4-month-old infants do not seem to perceive nonaligned surfaces as connected, even when the surfaces undergo common motion.

al information that specifies object unity. For example, they may have failed to note the common motion of the two rod pieces in the rod-and-box display (Slater, 1995; Wattam-Bell, 1991, 1992). This seems plausible in light of Aslin and Shea's (1990) findings that 6-week-olds apparently fail to detect velocities less than 9°/s, and that 12-week-olds fail to detect velocities less than 4°/s (the rod in the current displays moved at 4.8°/s). If the common motion of the rod pieces was not attended to, it does not seem surprising that they would not be ascribed to a single, partially occluded object.

Another account of the 2-month-olds' responses holds that infants at this age may be in the process of developing inferential abilities. That is, the emergence of conceptual skills, as opposed to strictly perceptual skills, supports the development of perception of object unity. (Inference in 2-month-olds has not previously been demonstrated, although Baillargeon & DeVos, 1991, found evidence of inference in some 3.5-month-olds.)

On this account, young infants' sensitivity to the visual information necessary to specify object unity may be in place at birth. By 4 months of age, infants are capable of inferring the hidden portion of the rod in the rod-and-box display (or at least inferring that the visible parts are connected, without a clear impression of the hidden region; Craton, 1993). Neonates, on the other hand, "appear to treat the visible evidence literally and do not seem to make perceptual inferences from visual input" (Slater, Morison, et al., 1990, p. 48). By 2 months of age, perhaps some infants can make inferences about unseen portions of objects (however, which infants these might have been was not discernible by available measures of maturity or sex).[3]

This account would seem to mitigate against Kellman and Spelke's (1983) view that infants are born with an unlearned tendency to experience objects as bounded, coherent, independent, and persisting over time (Spelke, 1985, 1988). However, their view does not make claims regarding infants' inferential abilities. It may be that neonates experience objects as Kellman and Spelke claimed, but their awareness does not extend beyond the information directly available. By 4 months of age, infants may be capable of using visual information in more abstract ways, such as inferring the existence of unseen portions of objects from the motions of those portions that are visible.

These interpretations are undertaken with caution, as there is currently no literature in support of these positions. More research is clearly needed to investigate developmental processes underlying infants' perception of object unity. These issues are especially elusive in that perception of object unity may depend on other skills, perhaps both perceptual and cognitive.

[3] A recent study of 2-month-olds' perception of object unity (Johnson & Aslin, in press) suggests that limitations in visual skills were responsible for the failure of the 2-month-olds to perceive object unity in our study. When 2-month-olds are presented with displays in which more of the rod is visible behind the box (relative to the displays in our study), they apparently perceive the two rod pieces as connected.

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