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Perceiving "Outside the Box" Occurs Early in Development: Evidence for Boundary Extension in Three- to Seven-Month-Old Infants

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This investigation examined whether infants display *boundary extension*—a tendency to remember more of a visual scene than was presented. Three- to 7-month-olds were familiarized with a photograph of a visual scene, and tested with wide-angle versus close-up views of the scene. Infants preferred the close-up, indicating that they perceived the wide angle (the one consistent with boundary extension) as more familiar. Converging experiments showed that: (a) infants did not spontaneously prefer the close-up, (b) adults did not judge the wide angle to be more similar to the familiarization stimulus, and (c) infants spontaneously preferred the close-up when the photographs depicted outline objects without backgrounds. The findings suggest that infants anticipate information that lies beyond the borders of a scene view.

A common theme running through the past 20 years of research on the early development of perceptual-cognitive abilities is that young infants possess abilities to structure and organize experience in ways that allow them to "go beyond the information given" (Bruner, 1957, 1973, 1992). With regard to the processing of visual-spatial patterns, for example, Ghim (1990) and Kavsek (2002) have reported that infants aged 3–4 months can connect the gaps between inducing elements to perceive subjective contours, with brain signals associated with the binding of the aligned elements in evidence in slightly older infants (Csibra, Davis, Spratling, & Johnson, 2000). Four-month-olds have also been found to be capable of representing the continuity of partly occluded objects (Kellman & Spelke, 1983) and the trajectory of completely occluded objects (Johnson et al., 2003). In addition, 3- to 4-month-olds have demonstrated an ability to abstract prototype structures representing the central tendency of a set of dot or face patterns (Bomba & Siqueland, 1983; de Haan, Johnson, Maurer, & Perrett, 2001; Quinn, 1987; Younger & Gotlieb, 1988). Even younger infants, 2-month-olds, have displayed abilities to form expectations of future events based on immediate past experience with predictable sequences of events, suggesting that rudimentary future-oriented processes are present quite early in life (Wentworth & Haith, 1992).

A type of extrapolation observed in adult scene representation is called *boundary extension* (reviewed in Intraub, 2007). When adults remember a photograph of a natural scene (particularly a close-up), they tend to remember having seen beyond the boundaries of the view. Projection of background objects and surfaces has been observed in: (a) drawings from memory (e.g., Intraub & Richardson, 1989), (b) scene reconstructions (assembling parts or adjusting the remembered position of the pictures' boundaries; Daniels & Intraub, 2006; Gottesman & Intraub, 2003; Intraub, Hoffman, Wetherhold, & Stoehs, 2006), and (c) recognition/rating tasks (e.g., Intraub, Bender, & Mangels, 1992). Boundary extension is not a general picture memory phenomenon, but one that occurs in memory for views of scenes (Intraub, Gottesman, & Bills, 1998). It is as if the visual system interprets a picture of a scene as a view of the world through a window—a situation in which the scene is understood to continue beyond the edges of the view. Indeed, boundary extension has been demonstrated in memory for regions of real three-dimensional scenes viewed through window-like apertures (Intraub, 2004). It occurs whether or not objects are cropped by the edges of a picture (Intraub & Bodamer, 1993), and whether or not the scene contains multiple objects (e.g., Intraub & Richardson, 1989) or a single object (Intraub, Gottesman, Willey, & Zuk, 1996). An example of one single-object scene and a typical drawing showing

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Figure 1. A single-object scene in which the object is not cropped by the edges of the picture (close-up view) and a representative drawing from memory (from Intraub et al., 1996, Figure 1, panels A and B).

boundary extension from Intraub et al. (1996), are shown in Figure 1.

Although originally observed following a 2-day lag (Intraub & Richardson, 1989), boundary extension does not require a lengthy retention interval. It has been observed within minutes (Intraub et al., 1992), and even seconds following presentation (Intraub et al., 1996, 2006). These temporal characteristics suggest a spontaneous formation of anticipatory projections that do not provide an accurate reproduction of the stimulus, but do provide a good prediction about the world the picture only partially reveals. Boundary extension can thus be thought of as an adaptive error in that it may increase the perceived coherence of a visual world that is otherwise constrained spatially by a limited visual field size and decreased visual acuity as one moves from the fovea into the periphery.

Little empirical work has been conducted to examine how boundary extension develops. The work that does exist suggests that boundary extension as evidenced with drawing reconstruction tasks is present as early as 6 years of age and as late as 84 years of age (Candel, Merckelbach, Houben, & Vandyck, 2004; Seamon, Schlegel, Heister, Landau, & Blumenthal, 2002). The status of boundary extension in younger perceivers remains uninvestigated, thereby leaving open the question of the ontogenetic origins of the effect.

In the present study, we investigated whether boundary extension could be observed in preverbal infants. Because drawings, reconstructions, or verbal response measures cannot be used with infants, we adapted the familiarization/novelty preference procedure, that has long been used to study recognition memory in infants (Fantz, 1964), to investigate boundary extension. Infants were familiarized with the stimulus shown in the middle panel of Figure 2. The stimulus is typical of many of the stimuli that have been used to generate boundary extension in adults in terms of depicting one or more objects in their natural background (e.g., Gottesman & Intraub, 1999). In addition, stuffed animal toys positioned in various locations in bedrooms or playrooms are likely to be common sights in the visual world of infants between 3 and 7 months of age. A stimulus depicting a stuffed animal toy (i.e., teddy bear) lo-

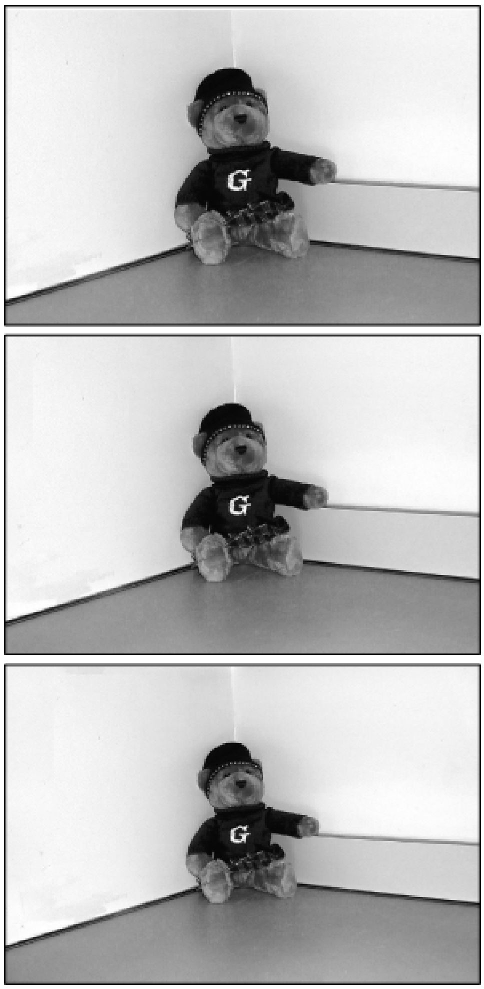

Figure 2. Black-and-white versions of the close-up test stimulus (top panel), familiarization stimulus (middle panel), and wide-angle test stimulus (bottom panel) presented to the infants in Experiment 1.

cated in the corner of a countertop thus seemed like a reasonable candidate stimulus for eliciting boundary extension in infants. After familiarization, the infants were preference tested with a picture depicting a more wide-angle view of the scene (10% more of the background; see Figure 2, bottom panel) and a picture depicting a more close-up view of the scene (10% less of the background; see the top panel of Figure 2). The rationale of this preference test is that if the infants remember the familiarization picture as having shown a more wide-angle view, then infants should perceive the wide-angle view as familiar and the close-up view as novel, resulting in a preference for the close-up view.

Experiment 1

Two age groups of infants were tested on the nonverbal recognition memory test of boundary extension: 3- to 4-month-olds and 6- to 7-month-olds. These two age groups were chosen because while a number of studies suggest that sensitivity to pictorial depth cues does not emerge until 6–7 months of age (Arterberry, Craton, & Yonas, 1993), other investigations indicate that three-dimensional information processing from pictorial depth cues can occur as early as 3–4 months of age (Bhatt & Waters, 1998; Bhatt & Bertin, 2001). Given that the ability to perceive the depth relations of the depicted objects would seem necessary for perceiving the familiarization and test stimuli as visual scenes (i.e., a teddy bear situated on a countertop), we thought it wise to begin our inquiry by testing both age groups.

Method

Participants. The participants were 48 healthy, full-term infants, twenty-four 3- to 4-month-olds (12 females, 12 males) with a mean age = 111.50 days, $SD = 9.67$ days, and twenty-four 6- to 7-month-olds (14 females, 10 males) with a mean age = 198.25 days, $SD = 11.77$ days. Eight additional infants were tested, but 3 failed to complete the procedure due to fussiness, and 5 were excluded from the data analysis because of position preference ($n = 3$), failure to compare the test stimuli ($n = 1$), and sibling interference ($n = 1$). Participants in all experiments were predominantly Caucasian and from middle-class backgrounds.

Stimuli. A scene was staged in which a main object (teddy bear) was seated in the corner of a countertop. A very wide-angle view was digitally photographed. Using Adobe Photoshop this image was cropped and then resized to create a "standard" view used for familiarization and two test views: a close-up view that showed 10% less background area than the standard (thus increasing object size by 10%), and a wide-angle view that showed 10% more background area (thus decreasing object size by 10%). All three images are shown in Figure 2. When printed, each image was 11.5 cm in length and 7.5 cm in height. Each of the three was centered and pasted onto a 17.7 cm × 17.7 cm poster board that was painted the same gray color as the visual preference testing apparatus.

The black and white depiction of the stimulus in Figure 2 may decrease the perceived richness of the actual stimuli. In the actual stimuli presented to the infants, the wall was cream colored, the baseboard of the wall was pink, the countertop surface was blue, the teddy bear's hat and sweater were maroon, and the fabric instantiating the furry body of the teddy bear was brown. The teddy bear was also photographed so that its skeletal configuration could further promote the organization of the space: The bear was seated upright against the vertical rise of the corner of the walls, the left arm of the bear was extended to highlight the spatial expanse of the right wall, and the legs of the bear extended out from the body along the countertop, thereby drawing attention to the flat horizontal surface of the countertop. The contrasting colors and careful positioning of the bear thus gave rise to a stimulus that was judged to be well defined in terms of its spatial structure.

Does the familiarization picture elicit boundary extension in adult viewers? As shown in Figure 1, a tight close-up view of a different toy bear elicited boundary extension when adults drew it from memory. However, the present design required the familiarization stimulus to be a mid-distance view. To determine whether this picture would elicit boundary extension in adults using a standard recognition procedure, Intraub et al.'s (1992) methodology was modified for use in a single-item recognition memory test. Participants were 18 undergraduate volunteers (15 females) seated in a classroom. To approximate the viewing conditions experienced by the infants (presentation medium and display distance), on each desk (placed face down so that the image could not be seen) was a copy of the familiarization stimulus printed on a sheet of paper. Participants were told that when cued by the experimenter they should turn over the paper (leaving it flat on their desk) and study the picture printed on the other side for 5 s, at which time they would receive another cue to turn it back over. They were instructed to pay attention to the entire picture (the background as well as the main object) and to remember it in as much detail as possible. They were told to try to create a "photographic image in their mind's eye," to help them remember the spatial layout of the scene in addition to the details. Following presentation, stimuli were replaced with a response sheet (face up) and a test picture (face down). Unbeknownst to the participant, the test item was identical to the familiarization stimulus.

Participants were instructed to wait until cued, then turn over the test picture and decide whether the view was "the same (0) as before," "a little more close-up (-1)," "a lot more close-up (-2)," "a little farther away ($+1$)," or "a lot farther away ($+2$)," and to mark their answer on the response sheet. They were also asked to provide a confidence rating of "sure (3)," "pretty sure (2)," or "not sure (1)." Boundary extension is considered to be in evidence if the mean boundary rating is shown to be significantly <0. Immediately following the instruction, participants turned over the test picture and entered their ratings on the response sheet. Although set size was only 1 item preceded by a short interval for test setup and instruction (4 min), most participants did not recognize that the view was the same as before: 50% rated it as being "a little more close-up," indicating that they remembered having seen a more wide-angle view (boundary extension), 39% rated it as "same," and 11% rated it as "a little farther away." The mean boundary rating, $-.39$ ($SD = 0.70$), differed significantly from 0, $t(17) = -2.36$, $p < .03$. The mean confidence rating was 2.0 ("pretty sure"). Both ratings are similar to those obtained in more traditional boundary extension studies. This test shows, that at least for adults, the familiarization picture was sufficient to elicit boundary extension.

Apparatus. All infants in each experiment were tested in a visual preference apparatus, modeled on the one described by Fagan (1970). The apparatus is a large, three-sided gray viewing chamber that is on wheels. It has a hinged, gray display panel onto which were attached two compartments to hold the poster board stimuli. The compartments are situated in front of and to the left and to the right of the infant, thereby allowing simultaneous presentation of two stimuli: either two identical copies of the same stimulus (as was the case during the familiarization trials) or two different stimuli (as was the case during the preference test trials). The reason for presenting two identical copies of the familiarization stimulus to the left and right of the infants is because if only a single stimulus, centrally located on the display panel, were presented, then the entire context of the preference test would be novel and might conceivably wash out any novelty associated with the test stimuli, per se. The stimuli were illuminated by a fluorescent lamp that was shielded from the infant's view. The center-to-center distance between compartments was 30.5 cm and on all trials the display panel was situated approximately 30.5 cm in front of the infant. There was a 0.62 cm peephole located midway between the two display compartments that permitted an observer to record the infant's visual fixations. A second peephole, 0.90 cm in diameter, was located directly below the first peephole, and permitted a Pro Video CVC-120PH pinhole camera (Speco Technologies, Amityville, NY) and a JVC video recorder (JVC company of America, Wayne, NJ) to record infants' gaze duration.

Procedure. All infants underwent the following general procedure. They were brought to the laboratory by a parent and seated in a reclining position on the parent's lap. There were two experimenters, both of whom were naive to the hypotheses under investigation. The first experimenter positioned the apparatus so that the midline of the infant's head was aligned with the midline of the display panel. When the display panel was open, the infant could see the experimenter from the midsection up in addition to a portion of the room that was a light background color. The experimenter selected the familiarization stimulus or test stimuli for the forthcoming trial and loaded them into the compartments of the display panel from a nearby table. The experimenter then appeared in front of the infant thereby eliciting the infant's attention and closed the panel, thus exposing the stimuli to the infant. The parent was unable to see the stimuli as a consequence of being blocked from the display panel by the external frame of the visual preference testing apparatus.

All infants were administered four 15-s familiarization trials. On each trial, the infants were presented with two identical copies of the familiarization stimulus (middle panel of Figure 2). Immediately after the familiarization trials, two 10-s test trials were administered in which a close-up view of the familiarization stimulus (top panel of Figure 2) was presented paired with a wide-angle view of the familiarization stimulus (bottom panel of Figure 2). The left–right positions of the close-up and wide-angle views were counterbalanced across infants on the first test trial and reversed on the second test trial. Familiarization and test trials of these numbers and durations have been used by the first author in a number of previous investigations (e.g., Quinn, 1994; Quinn & Bhatt, 2005).

During each trial, the first experimenter observed the infant through the small peephole and recorded visual fixations to the left and right stimuli by means of two 605 XE Accusplit electronic stop watches, one of which was held in each hand. The second experimenter timed the fixed duration of the trial and signaled the end of the trial. The first and second experimenters changed places for the test trials. The experimenter who presented stimuli and measured infant fixations during familiarization now measured trial duration and signaled the end of each test trial, whereas the second experimenter presented the test stimuli and measured infant fixations. The second experimenter was thus unaware of the nature of the stimulus that was presented to the infant during familiarization.

To handle possible side-biases (i.e., position preferences) sometimes displayed by individual infants, over all the trials, both familiarization and test, the looking time to one side (i.e., left or right compartment) of the display stage could not exceed 95% of the total looking time in order for the infant to be included in the data analysis. In addition, on preference test trials, each infant was required to look at both of the stimuli. Interobserver reliability for 24 randomly selected infants participating in Experiments 1 and 2 was later determined by comparing the looking times measured by the experimenter using the center peephole and an additional naive observer recording the looking times offline from videotape records, and averaged 0.92.

Table 1
Mean Fixation Times (Seconds) During the Familiarization Trials and Mean Preference Scores (Percentages) for the Close-up View During the Test Trials in Experiment 1

	Fixation time						
	Trials 1–2		Trials 3–4		Close-up preference		
Age	*M*	*SD*	*M*	*SD*	*M*	*SD*	t^a
3–4 months	9.61	3.25	9.28	3.20	63.76	12.58	5.36**
6–7 months	5.59	2.45	5.36	2.56	61.23	15.64	3.52*

Note. [a]*t* tests compared mean preference scores with chance performance.
*$p < .01$, **$p < .001$.

Results and Discussion

Familiarization trials. Individual looking times were summed over both stimuli on each trial, and then averaged across the first two trials and the last two trials. The mean looking times are shown in Table 1. An analysis of variance, Age (3–4 months vs. 6–7 months) × Trial block (1–2 vs. 3–4), performed on the individual scores, revealed only an effect of age, $F(1, 46) = 27.25$, $p < .001$, indicating that the younger infants looked more to the stimuli than did the older infants, a finding that is typical of prior reports of looking time performance for infants in this age range (e.g., Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002). Although the looking times declined nominally from the first to the last half of familiarization, the trial block effect was not significant. Because trial block effects have been observed in the past for infants presented with simple black-and-white visual patterns over the same number and duration of trials (Quinn, 1994; Quinn & Bhatt, 2005), we presume that the complexity of the stimulus in this instance (i.e., a realistic depiction of a visual scene rich in color, depth, and shape information) was sufficient to maintain infant attention across the familiarization period. However, despite the infant's continued attention to the stimulus across trials, processing had indeed occurred, as the preference data will show.

Preference test trials. Each infant's looking time to the close-up view was divided by the looking time to both test stimuli and converted to a percentage score. The data are reported in percentage scores rather than looking times because the duration of the test trials (i.e., 10 s) is shorter than the duration of the fixation trials (i.e., 15 s). The test trials were deliberately kept to a short duration to capture a presumed burst of differential responsiveness toward the novel versus familiar stimulus. If the test trials were made longer, any initial advantage in responsiveness to the novel stimulus could conceivably begin to subside because that stimulus is now becoming familiar. The mean preference scores for the two age groups are shown in Table 1. Comparison of the mean preference scores with the chance value of 50% revealed that the 3- to 4-month-olds and 6- to 7-month-olds preferred the close-up view. In addition, 20 of the twenty-four 3- to 4-month-olds and 19 of the twenty-four 6- to 7-month-olds displayed individual preference scores for the close-up view above 50%, $p < .007$, in both cases. The above-chance preference scores observed in both the group and individual data are consistent with the idea that boundary extension was occurring in both age groups.

Experiment 2

Experiment 2 examined an alternative explanation for the preference results of Experiment 1, namely, that the infants might simply have preferred the stimulus depicting the larger object with greater perceptual clarity. While preferences for large over small stimuli have been observed in infants, they have tended to be recorded for abstract black visual patterns presented on white backgrounds (Fantz & Fagan, 1975), rather than objects presented in the context of scenes. In addition, preferences for stimuli with greater clarity have tended to be observed at threshold rather than supra-threshold levels of visibility (Banks & Salapatek, 1981). Nevertheless, it seemed important to rule out the possibility that the preference for the close-up view did not reflect a spontaneous preference for the stimulus with the larger-sized object. To this end, Experiment 2 was conducted as a replication of Experiment 1, except that there were no familiarization trials.

Method

Participants. The participants were 48 healthy, full-term infants, twenty-four 3- to 4-month-olds (14 females, 10 males) with a mean age = 114.46 days, *SD* = 7.92 days, and twenty-four 6- to 7-month-olds (10 females, 14 males) with a mean age = 196.79 days, *SD* = 8.84 days. Four additional infants were tested, but 1 failed to complete the procedure due to fussiness, and 3 were excluded from the data analysis because of position preference ($n = 1$) and failure to compare the test stimuli ($n = 2$). None of the infants who participated in Experiment 2 participated in Experiment 1.

Stimuli. The stimuli were the test stimuli from Experiment 1.

Procedure. Each infant received two 10-s test trials during which the close-up view was paired with the wide-angle view. The test stimulus pairing was the same one presented to the infants in Experiment 1. Left–right positions of the close-up and wide-angle views were again counterbalanced across infants on the first test trial and reversed on the second test trial.

Results and Discussion

Each infant's looking time to the close-up view was divided by the looking time to both test stimuli and converted to a percentage score. The mean preference scores for the close-up view were 48.03 (*SD* = 17.01) for the 3- to 4-month-olds and 48.16 (*SD* = 18.10) for the 6- to 7-month-olds. Neither score was significantly different from the chance value of 50%, $t(23) = -0.57$ and -0.50, respectively, $p > .20$, in both cases. In addition, only 10 of 24 infants in each group displayed individual preference scores above 50%, $p = .54$, in both cases.

Given the mean spontaneous preference scores, it is necessary to consider further the preference scores from Experiment 1. When the preference for the close-up view after familiarization with the intermediate view was compared with the spontaneous preference for the close-up view, the difference was significant for both age groups: 3- to 4-month-olds, $t(46) = 3.64$, $p < .001$; 6- to 7-month-olds, $t(46) = 2.68$, $p < .02$. These results indicate that the preference for the close-up view observed in Experiment 1 cannot be attributed to an a priori preference for the close-up over the wide-angle view.

Experiment 3

In Experiment 3, we evaluated one additional alternative explanation for the results of Experiment 1. Although each of the test stimuli in Experiment 1 was physically 10% different from the familiarization stimulus (the main object was 10% larger in the close-up view and 10% smaller in the wide-angle view), it is possible that psychologically, the test stimuli were not perceived to be equivalently different from the familiarization stimulus. In particular, it is possible that the wide-angle view was perceived as more similar to the familiar view than was the close-up view, and the close-up view was preferred by the infants on the basis of its perceived greater discrepancy from the familiar view (McCall & Kagan, 1967).

Although one cannot obtain similarity judgments from infants, such judgments can be obtained from adults. Instead of testing memory (and the presence or absence of boundary extension), we asked adults to study all three views simultaneously to obtain a psychophysical estimate of whether the close and wide views were perceived as being equidistant for adult viewers. The technique of combining adult judgments and infant looking time responsiveness to a common set of stimuli to make inferences about infant performance has been used in a number of previous investigations of early perceptual-cognitive development (e.g., Kellman & Spelke, 1983; Quinn, Eimas, & Rosenkrantz, 1993; Ramsey, Langlois, Hoss, Rubenstein, & Griffin, 2004).

Method

Participants. The participants were 24 mothers of infants taking part in the first author's studies. They ranged in age from 23 to 34.

Stimuli. The stimuli were those used in Experiment 1.

Procedure. The three stimuli (familiarization, close-up, and wide angle) were presented to each participant in a horizontal arrangement. The familiarization stimulus was always presented in the center, and the left–right positions of the close-up and wide-angle stimuli were counterbalanced across infants. The familiarization stimulus was designated as the target stimulus, the stimulus on the left was identified as picture A, and the stimulus on the right was referred to as picture B. The participant was then asked to respond to the following question: As you look at the pictures, do you find that pictures A and B are equally similar to the target picture, or that one of them seems to be more similar to the target picture than the other? Participants could then answer with one of three responses: (a) pictures A and B are equally similar to the target picture, (b) picture A is more similar to the target picture, or (c) picture B is more similar to the target picture. The infants of the adult participants who were presented with these stimuli did not participate in either the spontaneous preference or familiarization tasks conducted with the same stimuli that are reported in this paper, thereby providing further assurance that the infant looking responses and adult judgments of the stimuli were independent of one another.

Results and Discussion

Of the 24 participants, 66.7% ($n = 16$) judged that the close-up and wide-angle views were equally similar to the familiarization stimulus, 25% ($n = 6$) judged that the close-up view was more similar to the familiarization stimulus than was the wide-angle view, and only 8.3% ($n = 2$) judged that the wide-angle view was more similar to the familiarization stimulus than was the close-up view. These results indicate that adults did not perceive the wide-angle view as being more similar to the familiarization stimulus than was the close-up. While the scaling results obtained from the adults cannot inform us directly of the perceptions of the infants in Experiment 1, the findings weaken support for the idea that greater perceived similarity of the wide-angle view to the familiar view can explain the preference for the close-up view observed in Experiment 1.

Experiment 4

As noted in the introduction, boundary extension is a phenomenon specifically associated with scene perception (Gottesman & Intraub, 2002; Intraub et al., 1998). It is not observed when layout information is removed from a picture; for example, line drawings of the main object and its layout yield boundary extension, but line drawings of the main object on a blank background do not (Intraub et al., 1998). Put simply, when adults remember pictures that depict a truncated view of an otherwise continuous world, they remember having seen a more expansive view than was shown. The purpose of Experiment 4 was to see whether we could obtain some converging evidence to suggest that infants had indeed perceived our stimuli as views of continuous scenes rather than simply as similar objects. We focused on the spontaneous preference task in Experiment 2, in which infants looked equally often at the close-up and wide-angle views of the bear. Would the same outcome occur if the scene context was removed and the same-sized bears were presented?

We filtered the photographs to create outline versions of the wide-angle and close-up bears, without including any background information (similar to Intraub et al., 1998). These stimuli are shown in Figure 3. The outline bears were the same size and bore the same spatial relation to the pictures' physical boundaries as the bears in the photographs. The outline stimuli were presented for two 10-s preference test trials. If infants showed no spontaneous preference because they were focusing on the identical objects in these simple scenes, then

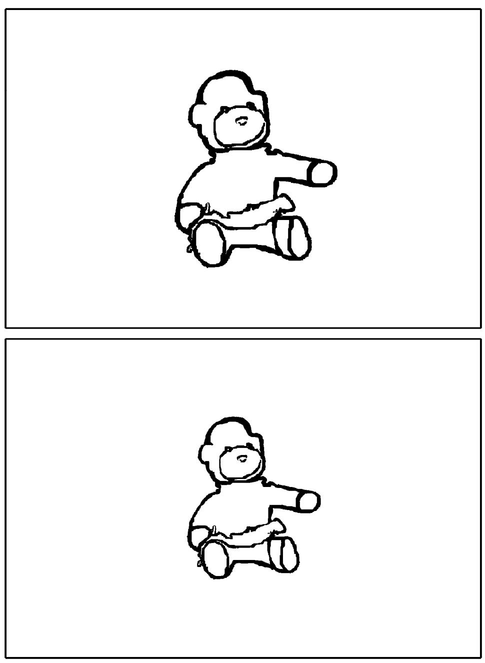

Figure 3. Close-up test stimulus (top panel) and wide-angle test stimulus (bottom panel) presented to the infants in Experiment 4.

the results should replicate those obtained in Experiment 2 (no preference). On the other hand, if like adults, infants distinguish between pictures that depict views of the world and those that depict objects in isolation, then the outline bears should be perceived differently. Based on prior work demonstrating size preferences for black-and-white visual patterns in infants (Fantz & Fagan, 1975), our expectation was that the infants would demonstrate a visual preference for the close-up bear.

Method

Participants. The participants were 48 healthy, full-term infants, twenty-four 3- to 4-month-olds (14 females, 10 males) with a mean age = 108.58 days, $SD = 7.25$ days, and twenty-four 6- to 7-month-olds (11 females, 13 males) with a mean age = 196.54 days, $SD = 15.26$ days. Four additional infants were tested, but did not complete the procedure due to fussiness. None of the infants who participated in Experiment 4 participated in Experiments 1 or 2.

Stimuli. The stimuli were the test stimuli from Experiment 1, except that the object was presented in black outline and the natural scene background was replaced with an all-white background. The outline drawings were created by filtering the photographs using Adobe Photoshop. This ensured that the outer edges of the outline bear were the same as the outer edges of the bear in the photograph used in the previous experiments. The stimuli are depicted in Figure 3.

Procedure. The procedure was identical to that used in Experiment 2.

Results and Discussion

The mean preference scores for the close-up view were 61.21 ($SD = 17.50$) for the 3- to 4-month-olds and 65.35 ($SD = 19.10$) for the 6- to 7-month-olds. Both scores were significantly different from the chance value of 50%, $t(23) = 3.14$ and 3.94, respectively, $p < .01$, in both cases. In addition, 19 of 24 infants in each age group displayed individual preferences for the close-up view above 50%, $p < .007$, in both cases. Moreover, when the mean spontaneous preferences are compared with those observed in Experiment 2, the differences are significant for both age groups: 3- to 4-month-olds, $t(46) = 2.63$, $p < .02$; 6- to 7-month-olds, $t(46) = 3.20$, $p < .01$. The spontaneous preference for the close-up view demonstrated by both age groups shows that these stimuli were treated differently from those in Experiment 2. Identical objects, with the same size relation to one another and the same spatial relation to the picture boundaries as the objects in Experiment 2, in this case were not of equal interest to the infants. Infants responded differentially to an outline bear stimulus presented without a background versus a bear stimulus presented in the context of a scene. This result suggests that infants in Experiment 2 may well have been responding to the pictures as views of a scene, and like adults in Experiment 1 they remembered these views with extended boundaries.

General Discussion

Four experiments were conducted to determine whether boundary extension occurs in infants in the age range between 3 and 7 months. The results of these experiments provide evidence that infants represent pictures of scenes in a way that is similar to adults. In Experiment 1, infants familiarized with a stimulus depicting a simple scene (i.e., teddy bear seated upright in the corner of a countertop) displayed a subsequent preference for a close-up over a wide-angle view of the same scene. Experiment 2 showed that the preference for the close-up view is not likely the result of an a priori preference and Experiment 3 provided evidence that adults do not judge the wide-angle view to be more similar to the familiar view than the close-up view. The results of Experiment 4 demonstrated that infants respond differentially when the teddy bear object was presented in outline form and removed from the context of the scene, thereby providing converging evidence that infants differentially process objects presented in isolation versus scenes displaying views of the world. The overall pattern of results suggests that in Experiment 1, after presentation with the familiarization stimulus, the wide-angle view was perceived by infants as familiar, and the close-up view was perceived as novel and consequently preferred. Because the wide-angle view depicted information that lay just beyond the borders of the familiar view, the conclusion is that boundary extension is present in infants as young as 3 months of age.

The results have implications for accounts of boundary extension in adults and picture perception in infants. First, because there was only a light memory load (i.e., a single stimulus was presented with no delay between familiarization and test trials) and no explicit instructions could be given to the young infant participants, the findings are consistent with the idea that the presentation of the familiarization stimulus may trigger the automatic activation of a perceptual schema that represents a greater spatial expanse than was provided in the original stimulus (Intraub, 2007). In this sense, boundary extension becomes a mechanism by which observers integrate spatially limited views of a surrounding world that can be perceived only a part at a time. Such a perceptual schema is believed to be adaptive for normal, healthy human adult observers who perceive the world through the constraints imposed by a limited visual field, and may be especially helpful for the anticipation of spatial layout in young infants, who have even more limited visual fields than adults (Dobson, Baldwin, Mohan, Delaney, & Harvey, 2003).

Given that the experiments reported here represent only a beginning inquiry into the possibility of boundary extension in infants, one can only speculate about the processing mechanisms giving rise to the hypothesized perceptual schema. At a bottom–up level, the introduction has already described the availability of Gestalt-based extrapolation mechanisms in infants in the age range at issue (e.g., Ghim, 1990). In addition, there is evidence that infants at 3 and 4 months of age can use lightness similarity to organize visual pattern information (Quinn, Burke, & Rush, 1993; Quinn & Bhatt, 2006), and it is possible that infants could use the lightness similarity of the wall surface to extend that surface beyond its pictorial border in their mental representation. At a top–down level, there is also evidence that infants can use acquired knowledge of specific objects and object kinds to help with the organization of visual displays (Needham, 2001; Needham, Dueker, & Lockhead, 2005; Quinn & Schyns, 2003; Quinn, Schyns, & Goldstone, 2006). It thus seems possible that infants could use their knowledge of room geometry to infer that walls continue beyond the constraints imposed by the visual field limitations of individual glances.

Second, the results suggest that, like adults, infants perceive a photograph as depicting part of a continuous scene, and may deploy projective processes that incorporate an expected continuity of the scene into their representation. This interpretation is supported by the finding that in adults, boundary extension does not occur for all types of pictures—only those that depict a truncated view of continuous space (Gottesman & Intraub, 2002; Intraub et al., 1998). The results of Experiment 4 also support this interpretation in showing that infants respond differentially when the objects are presented in outline form and removed from the context of the scene. The possibility that infants interpret picture views as depicting continuous scenes is consistent with other reports suggesting that infants in the same age range recognize the similarities between pictures and real-world referents. For example, DeLoache, Strauss, and Maynard (1979) demonstrated that 5-month-olds will generalize responsiveness from a real doll to a colored photograph of the doll, and Dirks and Gibson (1977) reported that same-aged infants transfer habituation from a live face to a photograph of that face. Although mature pictorial competence involving "dual representation" is considered to be a later acquisition (DeLoache, Pierroutsakos, & Troseth, 1996), the current results, as well as those of DeLoache et al. (1979) and Dirks and Gibson (1977), suggest that the ability to see through pictures to the real objects depicted in them may be an unlearned aspect of picture perception (Hochberg & Brooks, 1962).

Third, the fact that the pictures were apparently perceived as images depicting visual scenes is consistent with the possibility that the infants perceived the depth relations of the objects based on the cues available in the pictures (e.g., interposition, texture gradient). The findings are thus in accord with other reports suggesting an early onset for infants' ability to extract depth cues from pictures (Bhatt & Waters, 1998; Bhatt & Bertin, 2001). The later onset of pictorial depth perception reported by others (Arterberry et al., 1993) could reflect task demands such as whether the dependent measure involves looking or reaching (Keen, 2003; Munakata, McClelland, Johnson, & Siegler, 1997).

In addition to highlighting the possible implications of the findings, it is also important to acknowledge their limitations. Only a single stimulus scene was used in the study. This scene was typical of many of the scenes that have been shown to elicit boundary extension in adults (i.e., with one or more objects that were completely visible and depicted in their natural surroundings). On this basis, we do not see any reason why the effects that have been observed with the teddy-bear stimuli would not generalize to other scenes depicting common objects in familiar scenes. However, we concede that this remains an empirical question. In particular, whether boundary extension in infants will occur for more detailed backgrounds, or for novel backgrounds (as it does in adults, Intraub & Bodamer, 1993) is open to investigation. However these issues are resolved, alongside previous results showing that young infants can connect the inducing elements of a Kanizsa figure to perceive its subjective contours (Ghim, 1990), represent the continuity and trajectory of partly and completely occluded objects (Johnson et al., 2003; Kellman & Spelke, 1983), extract prototype representations from sets of exemplars (Bomba & Siqueland, 1983), and form future-oriented expectancies based on predictable temporal sequences (Wentworth & Haith, 1992), the demonstration of boundary extension in the first half-year of life provides another example of how infants cognitively structure information in ways that allow them to "go beyond the information given."

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