Developmental Science

Developmental Science 2017; 20: e12444 DOI: 10.1111/desc.12444

PAPER

Anticipatory scene representation in preschool children's recall and recognition memory

Erica Kreindel and Helene Intraub

Department of Psychological and Brain Sciences, University of Delaware, USA

Abstract

Behavioral and neuroscience research on boundary extension (false memory beyond the edges of a view of a scene) has provided new insights into the constructive nature of scene representation, and motivates questions about development. Early research with children (as young as 6–7 years) was consistent with boundary extension, but relied on an analysis of spatial errors in drawings which are open to alternative explanations (e.g. drawing ability). Experiment 1 replicated and extended prior drawing results with 4–5-year-olds and adults. In Experiment 2, a new, forced-choice immediate recognition memory test was implemented with the same children. On each trial, a card (photograph of a simple scene) was immediately replaced by a test card (identical view and either a closer or more wide-angle view) and participants indicated which one matched the original view. Error patterns supported boundary extension; identical photographs were more frequently rejected when the closer view was the original view, than vice versa. This asymmetry was not attributable to a selection bias (guessing tasks; Experiments 3–5). In Experiment 4, working memory load was increased by presenting more expansive views of more complex scenes. Again, children exhibited boundary extension, but now adults did not, unless stimulus duration was reduced to 5 s (limiting time to implement strategies; Experiment 5). We propose that like adults, children interpret photographs as views of places in the world; they extrapolate the anticipated continuation of the scene beyond the view and misattribute it to having been seen. Developmental differences in source attribution decision processes provide an explanation for the age-related differences observed.

Research highlights

- Preschoolers (4–5 years of age) exhibited anticipatory representation of scene structure, falsely remembering seeing beyond the boundaries of a photograph (boundary extension).
- Converging evidence for boundary extension is reported from a drawing task and a from a forced-choice recognition task that assessed view representation in working memory (closer vs. wider-angle views).
- For simple scenes, children and adults both exhibited boundary extension, but for complex scenes only children did (unless adults' stimulus duration was reduced).
- The age-related difference in boundary extension for complex scenes may reflect developmental differences in source attribution; with children being less adept at distinguishing *generated* from *perceived* scene information.

Introduction

Theories of perception have often noted, and grappled with, the dual representation inherent in photographs (Hecht, Schwartz & Atherton, 2003; Liben, 2003). In one sense, a printed photograph is a piece of paper containing visual information *within* its boundaries; in another sense, it is a representation of a place in the world that extends *beyond* its boundaries. Adults readily interpret photographs in terms of the latter. In fact, they often erroneously remember having seen the anticipated continuation of the scene, just beyond the original view-boundaries. This error of commission is referred to as *boundary extension* (Intraub & Richardson, 1989). To

Address for correspondence: Helene Intraub, Department of Psychological and Brain Sciences, University of Delaware, Newark DE 19716, USA; e-mail: intraub@udel.edu

illustrate, Figure 1 shows adults' drawings (middle row) of close-up photographs (top row) from memory. Inspection of scene content near the drawings' boundaries reveals information in each drawing that had no visual-sensory correlate in the close-up photograph, but comports well with the actual continuation of the view in the world (see Figure 1, bottom row). Converging evidence for boundary extension has been provided by a variety of recognition memory tests, including camera-distance rating tasks, and boundary reconstruction tasks (Hubbard, Hutchinson & Courtney, 2010; Intraub, 2010).

Do young children (e.g. 4–5-year-olds) extrapolate the likely layout of scenes when studying photographs? In early research, Seamon, Schlegel, Hiester, Landau and Blumenthal (2002) analyzed spatial errors in drawings made by children as young as 6–7 years of age. Drawing errors were consistent with boundary extension (reduced object size; more background space), but were also consistent with a variety of potential drawing artifacts, unrelated to memory – e.g. that children simply draw smaller objects (see Candel, Merckelbach, Houben & Vandyck, 2004; Seamon *et al.*, 2002). This issue was left unresolved. However, over the past 15 years, advances in research on boundary extension (in behavioral, neuropsychological and neuroimaging studies) and associated theoretical developments (Intraub, 2010, 2012; Maguire & Mullally, 2013) have led us to revisit the original question and to address new questions about anticipatory scene representation in children's memory. We report five experiments with 4–5-year-old children and adults in which we assess boundary extension using the drawing task from prior research (Experiment 1), and then implement a new working memory test for boundary extension that does not involve drawing ability (Experiments 2–5). In the following sections, we provide a brief overview of boundary extension and its theoretical implications, discuss related research with infants and children, and then present the rationale for each experiment.

Spatial construction in scene perception

Physiological limitations on vision prevent the observer from perceiving the surrounding world all at once. Movement of the eyes, head and body are required to sample surrounding space. A classic perceptual question is how these piecemeal inputs come to support a coherent, continuous, scene representation (Hochberg, 1986; O'Regan, 1992). The ability to rapidly anticipate the layout just beyond a given view may play an important role in scene representation (Intraub, 1997, 2012). Eye tracking studies using saccade-contingent displays have demonstrated that boundary extension can occur across the brief saccadic eye movement from one fixation to the next (Dickinson & Intraub, 2008; Intraub & Dickinson, 2008). This may facilitate scene perception during visual scanning, by priming upcoming layout (Gottesman, 2011). Anticipatory representation may also support navigation, when movement brings new regions into view; and support successful interaction with objects that are embedded within the scene's layout.

Boundary extension (memory for anticipated layout) appears to be driven more by spatial-cognitive characteristics of a scene than semantic characteristics. Familiar, common scenes are not required for boundary extension to occur. Robust boundary extension has been reported in memory for photographs presenting odd object-background combinations (e.g. 'bananas on rocks', 'light bulb on grass'; Intraub & Bodamer, 1993); and in memory for surfaces made of abstract shapes (McDunn, Siddiqui & Brown, 2014). Pictures of objects that do not include a background surface (e.g. a line-drawn object on a blank background) did not yield boundary extension, unless a surface was sketched into the background or participants explicitly imagined a background context for the object (Intraub, Gottesman & Bills, 1998; also see Gottesman & Intraub, 2002). Thus, in the case of 2D images, interpretation of the view as being part of a continuous world appears to be an important factor in eliciting boundary extension.

However, boundary extension is not limited to memory for 2D views nor is it limited to the visual modality. It occurs in memory for regions of the 3D world that are bounded by a window-frame-like apparatus (e.g. a 'kitchen counter scene' bounded by a frame), following either visual or haptic exploration (without vision) of the framed region. Participants, under these circumstances, remembered having *seen* or *felt* beyond the boundaries of the studied region, depending on modality (Intraub, 2004; Intraub, Morelli & Gagnier, 2015; and Mullally, Intraub & Maguire, 2012). When a 'haptic expert' – a woman deaf and blind since early life – explored the regions with her hands, she too experienced boundary extension, remembering having felt beyond the original view-boundaries in the absence of a corresponding sensory input (Intraub, 2004).

Research on brain areas associated with boundary extension indicates involvement of the hippocampus (thought to be associated with spatial representation and memory; e.g. Burgess, 2002; Maguire & Mullally, 2013), the parahippocampal cortex (PHC: thought to be involved in layout perception; Epstein, 2008, 2011), and the retrosplenial complex (RSC: thought to be

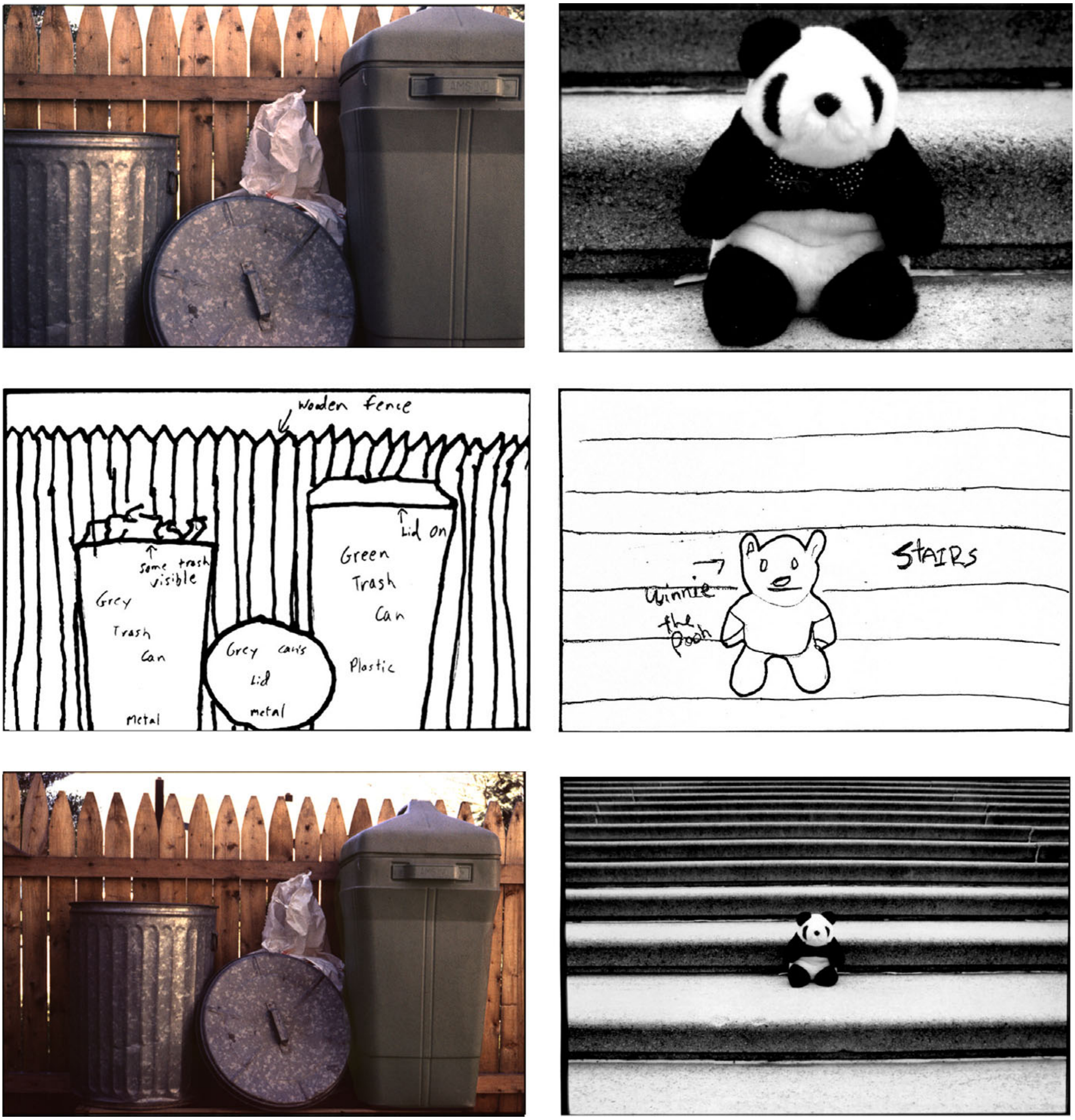

Figure 1 *Examples of boundary extension. The top row shows close-up views of scenes, the middle row shows participants' drawings from memory; note the continuation of scene at each boundary compared to the close-up. The bottom row shows the actual continuation of layout in the world. Left column includes part of Figure 1 from Intraub and Richardson (1989) and the right column includes part of Figure 1 in Intraub, Gottesman, Willey and Zuk (1996).*

involved in relating a view to its larger geographic context; Epstein, 2008, 2011). Patients with bi-lateral hippocampal lesions, who exhibited profound deficiencies in the ability to construct spatially coherent scenes in imagination, also exhibited *less* boundary extension than control participants on three different types of boundary extension tasks (Mullally *et al.*, 2012; also see Maguire, Intraub & Mullally, 2015).

Converging evidence for the role of hippocampus was provided by an fMRI study with healthy adults; in a brief-presentation boundary extension task, greater hippocampal activation was observed on trials on which boundary extension occurred than on those on which it did not (Chadwick, Mullally & Maguire, 2013). In other fMRI research, PHC and RSC both demonstrated sensitivity to the presence of boundary extension in a repetition attenuation paradigm (Chadwick *et al.*, 2013; Park, Intraub, Yi, Widders & Chun, 2007). Discussion of the benefits that neuroimaging may hold for understanding development of episodic memory (e.g. Mullally & Maguire, 2014) adds additional motivation for testing boundary extension in young children and creating more effective behavioral tests.

Mechanisms underlying boundary extension

The *multisource model* of a scene representation (Intraub, 2010, 2012; Intraub & Dickinson, 2008) provides an explanation of boundary extension that includes two stages. The first stage, *scene construction*, begins during scene perception. In addition to bottom-up processing of the visual information, top-down processes are initiated by the view. These include amodal continuation of background surfaces beyond the boundaries (Fantoni, Hilger, Gerbino & Kellman, 2008; McDunn *et al.*, 2014), and addition of anticipated content based on rapid scene classification and assessment of layout (Greene & Oliva, 2009) and object-to-context associations (Bar, 2004). This 'filling out' of the scene context is organized spatially, simulating the anticipated surrounding world. If children perceive the photographs as representing a place in the world, eliciting similar anticipatory activation, then boundary extension should be observed. If children perceive the printed photographs in our experiments as illustrated objects (similar to line-drawn objects on blank backgrounds in adults; Intraub *et al.*, 1998), scene construction beyond the view would not be expected.

If the photographs are interpreted as views of the world, thus initiating scene construction then, at retrieval, participants must determine how much of the entire representation corresponds to the photograph (i.e., the visual source alone). Assuming that different sources of information are not tagged as such in memory, participants must engage in decision processes to make this determination (i.e. *source monitoring*; Johnson, Hashtroudi & Lindsay, 1993). Misattribution of nearby constructed space from beyond the view-boundaries constitutes boundary extension. In terms of the current research, if children do automatically engage in scene construction, then developmental differences in source monitoring might affect how much boundary extension occurs.

Development of boundary extension

Quinn and Intraub (2007) studied the looking behavior of infants (3–4 months old and 6–7 months old) to determine whether their looking preferences might indicate boundary extension. In one experiment, infants in both age groups were presented with two pictures simultaneously, a closer and a wider-angle view of a toy bear in a room. No spontaneous preferences were observed. In another experiment, two new groups of infants were habituated to a view of the bear scene that fell midway between the closer and wider views, to establish memory for this middle view. When presented with the same closer–wider test pair as in the other experiment, preferential looking now emerged. Infants in both age groups looked longer at the closer view, suggesting that the habituated picture was remembered with extended boundaries, causing the wider-angle test picture to look familiar, and the closer test picture to appear 'novel' and draw attention.

However, infant looking behavior does not necessarily predict how 4–5-year-old children will interpret and remember photographs in an explicit memory test. If asked to memorize a card showing the basketball scene (Figure 2, Panel A), would a young child perceive the photograph as an illustrated card with an object so large that it almost touches the boundaries, or perceive it as a representation of a place in the world, initiating scene construction? In a study of photographic literacy, among the contrasts tested by Liben (2003), was children's ability to explain the difference between closer and wider-angle photographs in terms of how the photographs were made (relation of the camera to the real-world scene). She found that 7-year-olds rarely erred, 3-year-olds did not exhibit good comprehension, and that 5-year-olds showed mixed results, with about 50% providing appropriate characterizations. This raised our interest in how children 4–5 years of age would perform; might immature literacy in interpreting photographs curtail boundary extension?

The youngest children tested for boundary extension in previous research were 6–7 years old (Seamon *et al.*, 2002) and 10–11 years old (Candel *et al.*, 2004; Seamon *et al.*, 2002). In both experiments, on each trial, participants studied a photograph of a simple scene for 15 s, and then drew it from memory in a response box that was the same size as the photograph. Consistent with boundary extension, participants reduced the size of the

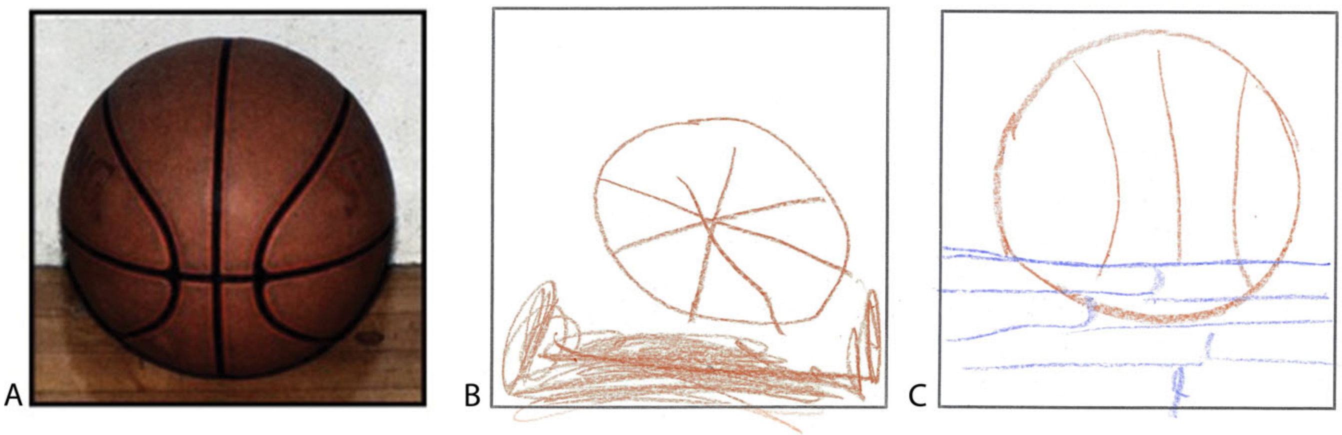

Figure 2 *The stimulus photograph (Panel A), a child's drawing (Panel B), and an adult's drawing (Panel C); each drawing reflects the group mean. The photograph and the response boxes in which each drawing was made included a 1" margin (about 2.54 cm) when printed.*

objects, increasing the amount of surrounding background space – creating a more 'wide-angled' view. However, without converging evidence from a recognition memory test that does not involve drawing ability (as in adult research; Intraub & Richardson, 1989), the authors could not determine whether the spatial errors observed reflected errors of memory (boundary extension) or drawing artifacts (e.g. drawing ability, drawing conventions, and so forth; Candel *et al*., 2004; Chapman, Ropar, Mitchell & Ackroyd, 2005; Seamon *et al*., 2002).

The researchers recognized this limitation, explaining that recognition memory tasks central to the adult literature were simply too complex for young children to understand. For example, Intraub and Richardson's (1989) 'camera distance' task required participants to rate test pictures on a 5-point scale to indicate if the test view is the 'same', 'more close-up' or 'farther away' than in the stimulus view. Simple binary choice recognition tests were avoided in adult research because variability across individuals and across scenes make it unclear how to best choose foils that would provide a sensitive test.

To address this problem, Chapman *et al*. (2005) created a dynamic recognition test to circumvent the drawing problem with older children. Participants viewed a photograph and at test adjusted the zoom factor on a test picture to make it match memory. They tested a heterogeneous group of older children (9–16 years old), and included both children diagnosed with Asperger's syndrome and normally developing children. Both groups tended to 'zoom out' the picture, revealing more surrounding space (boundary extension). Although promising, we were concerned that for very young children, 4–5 years old, the zoom function might be too interesting in and of itself, distracting them from the memory task, and that the continuously changing stream of closer and wider views might cause confusion. We had the same concern for other dynamic tasks used to test boundary extension (e.g. border adjustment; Intraub, Hoffman, Wetherhold & Stoehs, 2006). This motivated us to develop a new static recognition memory task for the current series of experiments.

The current investigation

Across experiments, we tested boundary extension in children (4–5 years old) and adults. In Experiment 1, we tested free recall using a drawing task. In Experiments 2–5 we implemented a new, immediate two-alternative forced-choice (2AFC) recognition test, and a guessing task to test for potential selection bias. In Experiments 1–3 we presented simple scenes, similar to those used in previous boundary extension experiments with children. In Experiments 4–5 we increased scene complexity, presenting more distant views with multiple objects and more complex backgrounds. The specific rationale for each experiment is described in turn.

Experiment 1

The primary purpose of Experiment 1 was to attempt a replication of prior boundary extension research with older children (Seamon *et al*., 2002; Candel *et al*., 2004) with our participants and our stimulus (a tight close-up of a basketball in a gym; Figure 2, Panel A). The secondary goal was to include a new object-drawing task to allow us to test children's (and adults') use of space when drawing a round object (a 'happy face'), independent of remembering a studied scene. The object-drawing task preceded the critical scene-drawing task so that participants would not be biased to think of the picture as a scene. As a free drawing task, it also served to put the children at ease and to familiarize them with the response box.

Method

Participants

Thirty children (12 females) enrolled at the University of Delaware Early Learning Center were invited to participate; two children (one of each gender) declined or didn't follow instructions. Thus, 28 children participated (M = 4.66 years old; range = 4.14–5.30 years old). Adult participants were 26 University of Delaware undergraduates (19 females) who volunteered for the Research Pool in the Department of Psychological and Brain Sciences to fulfill a course requirement (M = 18.69 years old, range = 18–21 years old).

Stimuli

Two 6″ ×6″ (15.2 cm × 15.2 cm) color digital photographs were printed on Hammermill Color Laser Gloss paper using an HP LaserJet printer. There was a 1″ (2.54 cm) margin around each printed photograph. One was a sample photograph ('two children on swings') and the other photograph was the stimulus ('basketball in a gym'; shown in Figure 2, Panel A).

Apparatus

A stopwatch was used to time stimulus presentation. Crayons were provided for drawing. Response sheets included a 6″ × 6″ (15.2 cm × 15.2 cm) outline square on white paper with a 1 inch (2.54 cm) margin similar to the stimulus. Chairs and a table were similarly arranged in the Early Learning Center for children, and in our lab for adults.

Procedure

Participants were run individually. They were presented with the sample picture ('two children on swings'). To draw attention to the photograph as a whole and ensure that participants understood our terminology, all participants were asked to point to the 'edges of the picture', and to describe everything they saw. We then proceeded to the two main tasks. Instructions were the same for both age groups. We explained to adults that simple wording was being used because we were also testing preschoolers. The object-drawing task and the scene-memory task followed in turn.

In the *object-drawing task*, participants were presented with one of the response sheets, referred to as an 'empty picture'. They were asked to point to the edges of the empty picture (the black outline box), and were asked to draw a 'nice, big, round happy face'.

In the *scene-memory task*, participants were presented with the basketball picture (Figure 2, Panel A) and asked to point to the edges of the picture and describe everything up to the edges, including size. Toward the end of the 15-s presentation, the experimenter and participant together counted to three and said 'click' (in the context of the 'game' this indicated that the participant had taken a mental snapshot of the picture). The photograph was replaced by a fresh response sheet. Participants were asked to point to the edges of the 'empty picture' and fill the empty picture with a drawing of the photograph with the 'nice, big, round basketball'. They were told to use their memory to draw it so the space was filled just the same as in the photograph. Use of the same adjectives in describing the face and the ball was done to avoid creating bias.

Results and discussion

Drawings from both tasks were digitized. The number of pixels in the object were counted using Adobe Photoshop (CS5). We will report the results of the memory task followed by the results of the object-drawing task.

Memory task

During presentation, all children described the ball, the wood floor and the white wall. After drawing, they pointed out the ball, the floor and the wall (which they did not color because the paper was also white) in their drawing. All but one child drew the wooden floor (this child, nonetheless, pointed to the bottom of the drawing, saying it was a wood floor). The area of the object in the drawing (measured in pixels) was divided by the area of the original object in the photograph (measured in pixels) to determine what is usually referred to as the 'proportion drawn' (Intraub & Bodamer, 1993; Mullally *et al.*, 2012; Seamon *et al.*, 2002).

Figure 3 shows the mean proportion drawn for both age groups (error bars signify the .95 confidence interval); children and adults both reduced the size of the basketball in the scene. Figure 2 shows the photograph (Panel A), a child's drawing (Panel B), and an adult's drawing (Panel C) – each reflects the mean of that group.

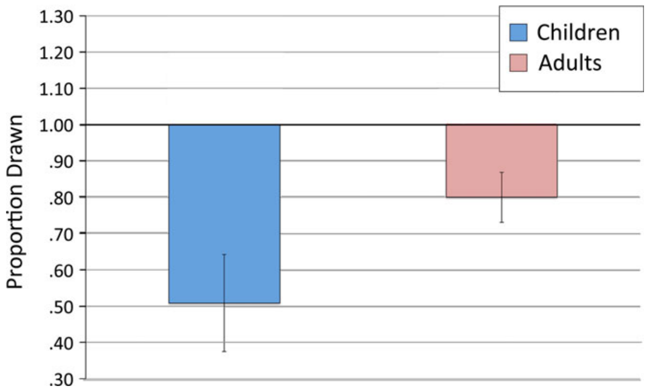

Figure 3 *Mean proportion drawn for each age group; error bars show the .95 confidence intervals. Both groups reduced object size (proportion drawn < 1.00) and included more background area than in the photograph (Experiment 1).*

As in Seamon *et al*. (2002), size reduction was greater in children's drawings than in adults' drawings, $t(53) = 2.82$, $p < .001$, $d = 1.5$.

Object-drawing task

Figure 4 shows a child's drawing (Panel A) and an adult's drawing (Panel B) of the 'happy face' (representative of each group's mean object size). Because the instruction was verbal, there was no 'original object size' with which to compare participants' drawings. Instead, we divided the number of pixels in the object by the total number of pixels in the response box to obtain the proportion of the picture space their drawn object filled. The mean proportion was .46 ($SD = 0.23$) for the children and .62 ($SD = 0.17$), for the adults; these differed significantly, $t(53) = 2.81$, $p < .01$, $d = .8$.

Figure 5 shows the proportion of the picture space covered by the basketball and by the happy face for each age group. A 2 (children vs. adults) × 2 (object-drawing task vs. scene-memory task) mixed measures ANOVA showed that overall, the object drawn in the scene-memory task (basketball) was smaller than the object drawn in the object-memory task (happy face), $F(1, 53) = 30.90$, $p < .001$, and there was no *group* × *task* interaction, $F(1, 53) < 1$. This demonstrates that when participants reduced the size of the basketball in the scene drawings, this was not due to an inability or unwillingness to draw a larger object in the response box.[1] Taken together, these results suggest boundary extension in both groups. Children did draw smaller basketballs than the adults (similar to Seamon *et al.*'s, 2002, observation), but we cannot conclude from this that the children exhibited greater BE, because they drew smaller objects in the object-drawing task, as well, $F(1, 53) = 501.69$, $p < .001$.

Experiment 2

Experiment 2 immediately followed Experiment 1. Here we sought to determine whether converging evidence for boundary extension would be obtained in a two-alternative forced-choice (2AFC) recognition memory task that did not involve drawing. On each of 40 trials,[2] a target scene (either the closer or the wider view of a pair) was presented for 15 s. The card was then replaced (requiring approximately 2 s) with a card that included the target and either a closer or wider view of the same scene. Without boundary extension, the error rate (selecting the incorrect picture in the test pair) should be the same for close-up targets and wider-angle targets. If boundary extension occurs, then the error rate should be asymmetrical; participants should erroneously reject the *identical* view when the target was a close-up (selecting instead the more expansive, wider-angle foil) than when the target was a wider-view (selecting instead the less expanse, closer foil).

To increase the chance that our distractor choices would be sensitive enough to detect boundary extension, we created *high-similarity* and *low-similarity* pairs for each scene. In high-similarity pairs, the wider view was zoomed out to show 13% more of the scene, whereas in the low-similarity pair it was zoomed out to show 30% more of the scene.

Method

Participants

Participants in Experiment 1 began Experiment 2 as soon as Experiment 1 was completed. Three children (two female) chose not to complete Experiment 2 (defined as responding to at least 32 of the 40 trials). Thus 26 children (mean age = 4.65 years, range = 4.14–5.30 years) and all 26 adults completed Experiment 2.

[1] An interesting observation is that adults' 'happy face', like the basketball in the photograph, filled 62% of the picture, yet adults drew a smaller basketball when remembering the scene.

[2] We anticipated that our participants would be able to handle this number of trials, because Lloyd, Doydum and Newcombe (2009) used a similarly large set of picture trials in their research on memory for objects and color-background combinations in 4-year-olds.

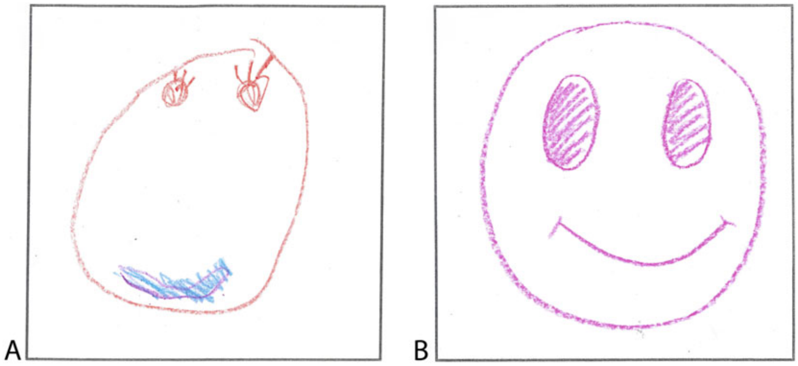

Figure 4 *A child's drawing (Panel A) and an adult's drawing (Panel B) of a 'happy face' in the object drawing task; each drawing reflects the group mean (Experiment 1).*

Stimuli

Stimuli were 40 simple scenes. Most showed a single main object on a natural background; four showed a single object-cluster on a background ('dice', 'boots', 'roller coaster car containing a family', 'children sitting with a dog'). Three different versions of each scene were created using Adobe Photoshop: a close-up view and two wider-angle views (the high-similarity view, which included 13% more of the scene than the close-up, and the low-similarity view, which included 30% more of the scene). Figure 6 shows an example of high- and low-similarity pairs for one of the scenes.

All pictures were individually printed using the same paper as Experiment 1. Each printed image was 3″ × 3″ (7.62 cm × 7.62 cm); these printed cards served as target pictures. The high- and low-similarity pairs were vertically aligned: the size of these cards was 3″ by 6″ (7.62 cm × 15.24 cm). All tests pairs were printed twice, once with the close-up on top and once with it on the bottom.

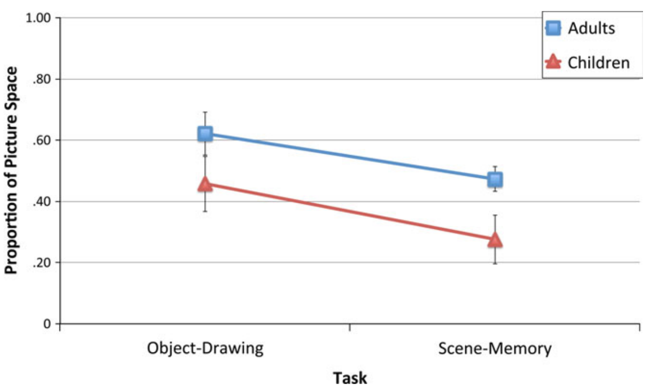

Figure 5 *The mean proportion of the picture filled by the object in the object-drawing task (draw a 'nice, big, round happy face') and the scene-memory task (draw the scene with the 'nice, big, round basketball') for children and adults. Error bars show the .95 confidence interval for each mean (Experiment 1).*

Design

There were 40 trials. On *close trial*s, the target picture was the close-up and on *wide trials* it was the wider view; close and wide trials were presented equally often. Half the time the pairs were high-similarity pairs and half the time they were low-similarity pairs. The order of the scenes was always the same. Half of the target pictures were always associated with the correct answer being at the top of the test card and half were always associated with the correct answer being at the bottom of the test card (for example, the correct answer for the 'cat scene' shown in Figure 6 was always on the bottom across counterbalancing orders).

There were four counterbalancing orders to ensure that across participants each scene appeared equally often as a close-target and as a wide-target, and equally often in the context of a low-similarity and a high-similarity comparison. For example, for the 'cat scene' shown in Figure 6, in counterbalancing 'Order 1', the close-up was the target (low-similarity pair), in 'Order 2', the wider view was the target (low-similarity pair), in 'Order 3', the close-up was the target (high-similarity pair), and in 'Order 4', the wider view was the target (high-similarity pair). No more than two of the same trial type (close trials or wide trials) and no more than two of the same correct answer location (top or bottom) appeared in a row. For children, the 40 trials were divided between two sessions (each lasting approximately 20 minutes separated by two to four days, depending on the child's availability). Adults completed all trials in a single session (within 30 minutes).

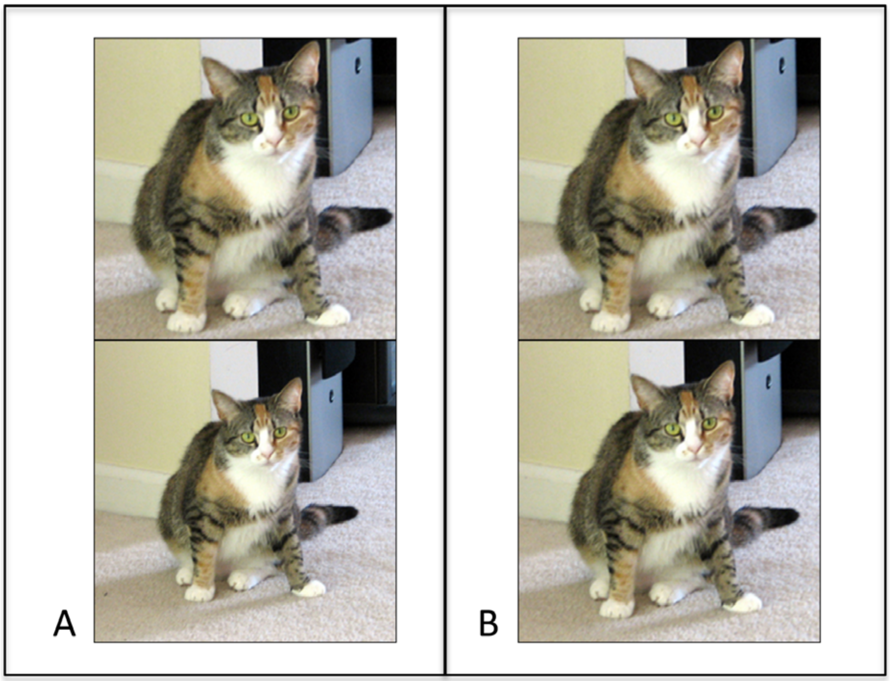

Figure 6 *An example of the simple scenes used in Experiment 2. Panel A shows a low-similarity test pair (the wider view shows 30% more of the scene than the close-up) and Panel B shows a high-similarity test pair (the wider view shows only 13% more of the scene than the close-up). In this example the close-up appears at the top of each pair and wider view appears at the bottom.*

Procedure

There were two parts to the procedure. First we conducted a *perceptual matching task* to ensure that participants could match a target view to its identical copy in the test pair when the target and test pair were all simultaneously visible. There were six trials, three with close-up targets and three with wider-angle targets (high-similarity and low-similarity pairs were included). We set a criterion of five correct trials for a child to progress to the memory experiment (no feedback was provided during the test).

The second part of the procedure was the recognition memory experiment (40 trials). Here, the target picture (presented for 15 s) preceded the test pair by approximate 2 s (the time it took to flip the single card and replace it with the test card). While the stimulus was visible, the participant was instructed to describe the scene and to take a 'mental snapshot'. As in Experiment 1, at the end of each 15-s stimulus presentation, the experimenter and the participant counted to three and said 'click' to signify the mental snapshot. If interest began to flag over trials, a monkey puppet was introduced who asked about the game and requested permission to watch. Like the children, adults were also asked to describe the stimulus during presentation (a departure from the typical adult procedure in boundary extension research).

Results and discussion

All children passed criterion on the perceptual matching task (18 made no errors); adults made no errors. In the memory task, all adults and all but one child completed all 40 trials; this child completed 32 trials, which met our a priori criterion for inclusion.

The proportion of errors for each group as a function of trial type (close or wide) and test pair similarity (low or high) is shown in Figure 7. The confidence interval around each mean shows that children made a statistically significant number of errors in each condition (i.e. greater than 0). Close-up trials were particularly difficult; they rejected the identical close-up so frequently that performance did not differ from chance (.50). This occurred, even though the object in each close-up was so large, it almost touched the boundaries. Adults also had difficulty on the close trials, frequently rejecting the identical close-up; whereas on wider-angle trials their error rate did not differ from zero.

A 2 (children vs. adults) × 2 (close trials vs. wide trials) × 2 (high-similarity vs. low-similarity) mixed

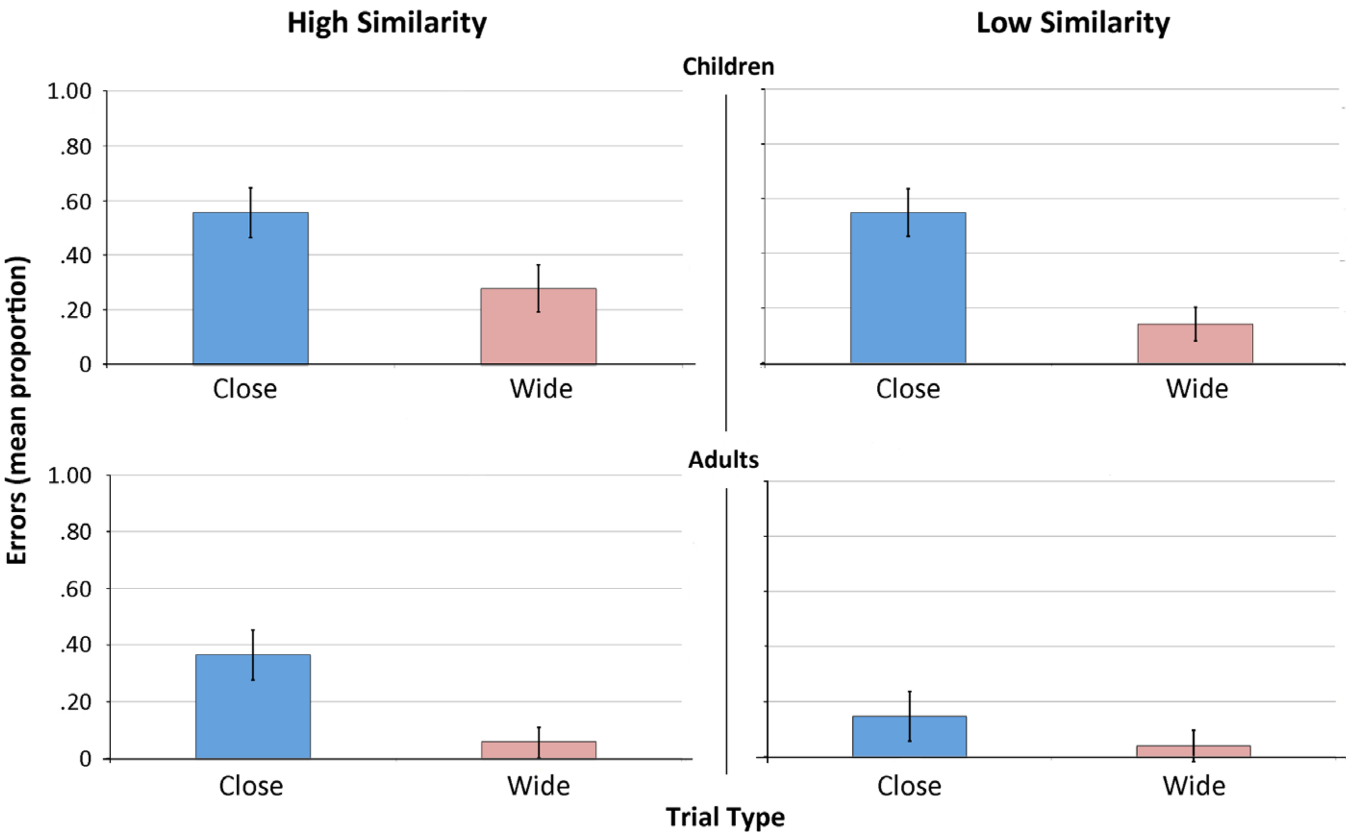

Figure 7 *Mean proportion of errors on close trials (close-up was the target) and wide trials (wider-view was the target), as a function of test picture similarity (high vs. low) and age group (Experiment 2). Error bars show the .95 confidence interval around each mean. A greater proportion of errors on close trials indicates BE.*

measures ANOVA was conducted on the mean proportion of errors. Not surprisingly, children made more errors overall, than did adults, $F(1, 50) = 14.70$, $p < .001$. The critical main effect of trial type (close trials vs. wide trials) was significant, $F(1, 50) = 62.86$, $p < .001$; participants erred more frequently on close trials (selecting the wider view) than on wide trials (selecting the closer view), demonstrating the error asymmetry diagnostic of boundary extension. More errors were made on high-similarity trials than on low-similarity trials, $F(1, 50) = 17.25$, $p < .001$, with no *similarity* × *age* interaction, $F(1, 50) = 1.09$, $p = .30$, indicating that both groups were sensitive to the spatial differences between high- and low-similarity comparisons. As shown in Figure 7, the difference between trial types appeared greater for children than adults, but this *age* × *trial type* interaction did not reach significance, $F(1, 50) = 3.77$, $p = .06$. Finally, there was a significant three-way interaction (*age* × *trial type* × *similarity*), $F(1, 50) = 18.16$, $p < .001$. Inspection of Figure 7 suggests that this was due to children showing a greater difference in error rate on low-similarity trials (reflecting a reduction in errors on wide trials), whereas adults showed a greater difference on high-similarity trials (because they rarely made errors on low-similarity trials).

In sum, the pattern of errors indicated that both age groups exhibited BE. However, before accepting this conclusion, we tested a potential alternative explanation of the children's data in Experiment 3.

Experiment 3

The purpose of this experiment was to determine whether children's error asymmetry in Experiment 2 might have reflected a selection bias (favoring wider views) rather than a true memory error. We are not suggesting that the children in Experiment 2 were simply guessing when they responded because, like the adults, they were sensitive to the spatial differences between test pictures, making more errors on high-similarity than low-similarity trials. However, on trials on which they were *unsure*, a selection bias favoring the wider view would lead to the same asymmetrical error pattern observed in Experiment 2. Experiment 3 tested for such a bias by asking children to guess which photograph (the closer or wider view) they thought an adult confederate was observing on each of 40 trials.

Method

Participants

Of the 26 children who participated in Experiment 2, 20 (11 females) returned to participate in the current experiment. This experiment was conducted 5–6 months after Experiment 2, and six children (females) were no longer enrolled at the center. We replaced them with six females from the younger half our 4–5-year-old age range (M = 4.30 years, range = 4.07–4.50 years). Across all participants the mean age was 4.92 years old (range = 4.07–5.74). We also analyzed subgroups of participants. One subgroup included *only* those 20 children who had participated in Experiment 2 (M = 5.10, range = 4.70–5.74) and the other included *only* those 20 who fell between the ages 4–5 (M = 4.68, range = 4.07–4.98).

Stimuli

Forty new scenes were selected, each matching a scene from Experiment 2 in terms of category and object size. High-similarity and low-similarity pairs were created as in Experiment 2. An additional six new scenes, similar to those in Experiment 2, were created for the perceptual matching task.

Design and procedure

The difference between Experiment 2 and 3, aside from the stimulus set, was that the target card was viewed *only* by an adult confederate who stood at a distance with her back turned to avoid unintended facial feedback and to prevent the children from seeing the content of their cards. Participants sat at the table and pointed to the picture on the test card that they *guessed* the adult was looking at on each trial.

Results and discussion

All participants passed criterion on the perceptual matching task (20 children made no errors) and moved on to the guessing game experiment. Children did *not* exhibit a selection bias favoring the wider view, but did show a guessing bias that favored the *closer* view. They selected the closer view on 60% of the trials, which differed significantly from chance (50%), $t(25) = 2.67$, $p = .01$. The same bias occurred on low-similarity and high-similarity trials, with participants selecting the closer view 62% and 58% of the time, respectively; with no significant difference between them, $t(25) = 1.15$, $p < .26$.

We conducted two further analyses. We analyzed data only from children who had also participated in Experiment 2 (n = 20). On average, they selected the close view more frequently (58% of the trials), an error rate showing the same trend, but that did not differ significantly from chance (50%), $t(19) = 2.07$, $p = 0.052$. We also analyzed data from those children who fell between the ages of 4 and 5 (n = 20), and they too selected the close view more frequently (60% of the trials), which differed significantly from chance (50%), $t(19) = 2.19$, $p = .04$. These results suggest that the error asymmetry favoring selecting the *wider* views in the recognition test (Experiment 2) did not reflect a guessing bias. If anything, children had to overcome a guessing bias favoring the close-up to erroneously select the wider-angle view at test.

Experiment 4

The success of the 2AFC procedure allowed us, for the first time, to test children's spatial memory for complex, multi-object views of the world. All prior boundary extension research with children has focused on very simple scenes such as those in Experiments 1–3. In light of evidence that young children may have a smaller working memory capacity than adults (Cowan, AuBuchon, Gilchrist, Ricker & Saults, 2011; Cowan, Hismajatullina, AuBuchon, Saults, Horton *et al.*, 2010), we wondered if presentation of multi-object views might tax children's working memory or distract their attention from the scene as a whole during encoding. If so, we might observe poor memory, which would result in chance performance, rather than the error asymmetry that characterizes boundary extension. If despite the relative complexity of the new scenes, children perceive each as a single coherent view of the world, they might exhibit boundary extension, as in Experiment 2. We added a six-item 'guessing game' task at the end of each child's session to assess the presence of a guessing bias (as in Experiment 3).

Method

Participants

Thirty-five new children (21 females) were invited to participate; four did not pass criterion on the perceptual matching task and four did not complete the experiment and were replaced. Thus, 26 children (M = 4.36 years, range = 4.01–5.02 years) participated in the memory experiment. Twenty-six young adults (12 females) from the same population described earlier participated (M = 18.62 years, range = 18–25 years).

Stimuli

Forty new photographs of scenes with multiple objects and relatively complex backgrounds served as stimuli in the memory test. Closer and wider views were sized as in Experiment 2. A low-similarity (Panel A) and high-similarity test pair (Panel B) for one of the scenes is shown in Figure 8. An additional 12 new scenes were created and sized as in Experiment 2, half for the perceptual matching task, and half for the 'guessing game' task.

Design and procedure

Other than the picture set and the addition of the guessing game task at the end of the children's sessions, the design and procedure were the same as in Experiment 2.

Results and discussion

In the perceptual matching task, four children did not pass criterion with the complex pictures and were replaced. Of the 26 children who passed criterion, 20 correctly responded on all trials. Adults made no errors. These children and adults proceeded to the memory task. All participants completed all 40 trials.

Most adults made few if any errors; boundary extension did not occur. On low-similarity trials, the proportion of errors was only .03 (close-up trials) and .02 (wide-angle trials); and these did not differ significantly, $t(25) = 1.14$. On the more demanding, high-similarity trials, the proportion of errors was only .15 (close-up trials) and .08 (wide-angle trials), and these did not differ significantly, $t(25) = 1.47$; thus there was no adult boundary extension to compare with children's performance. We therefore analyzed children's data separately.

Children's proportion of errors on close and wide trials when high-similarity and low-similarity test pairs were presented is shown in Figure 9. A two-way repeated measures ANOVA, Trial type (close trials vs. wide trials) × Similarity (high vs. low) showed that the children

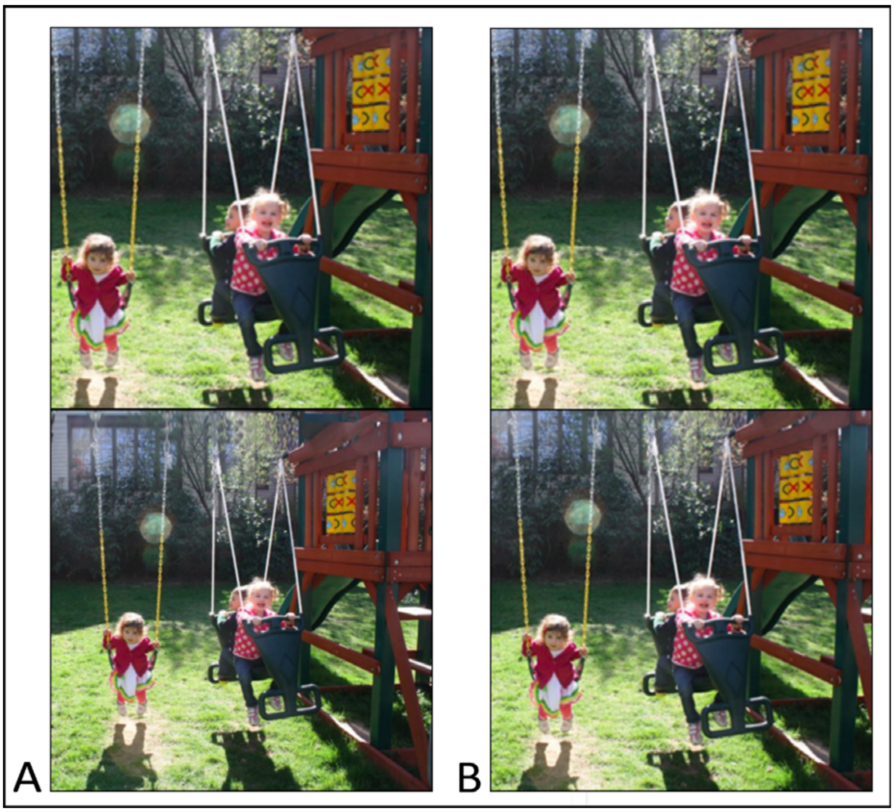

Figure 8 *An example of the multi-object scenes used in Experiment 4. Panel A shows a low-similarity test pair (the wider view shows 30% more of the scene than the close-up) and Panel B shows a high-similarity test pair (the wider views shows only 13% more of the scene than the close-up). In this example the close-up appears at the top of each pair and wider view appears at the bottom.*

exhibited the response asymmetry diagnostic of boundary extension; they made more errors on close trials than on wide trials, $F(1, 25) = 11.89$, $p = .002$. Again, children were sensitive to the subtle spatial differences between test pairs, making more errors on high-similarity trials than on low-similarity trials, $F(1, 25) = 4.37$, $p = .047$. There was no significant *trial type* × *similarity* interaction, $F(1, 25) = 2.06$, $p = .163$.

All but one child (female) completed the guessing task. As in Experiment 3, they exhibited a guessing bias opposite boundary extension – favoring *close-up* views. They guessed that the adult confederate was observing the *closer* view on 65% of the trials, which differed significantly from chance (50%), $t(24) = 3.02$, $p < .01$.

In sum, children exhibited boundary extension under conditions in which adults *did not*. The reason that adults performed so well with these stimuli is likely because they were more wide-angle views than in Experiment 2. For adults, it has been well established that boundary extension decreases as views widen (Intraub, Bender & Mangels, 1992; see Hubbard *et al.*, 2010 and Intraub, 2002, for reviews). The long viewing time (15 s) may have allowed implementation of strategies that overcame this relatively weak boundary extension. We tested this hypothesis in Experiment 5.

Experiment 5

In Experiment 5, a new group of adults viewed the same complex scenes as in Experiment 4, but stimulus duration was reduced to minimize implementation of strategies (e.g. 'the tree is 8 mm from the left boundary'). In prior single-trial tasks with adults, very brief stimulus durations (e.g. 250 ms; Intraub & Dickinson, 2008) were presented in part to avoid such strategies. We could not implement such brief durations while maintaining the same method as Experiment 4 (cards on a table); thus we reduced the duration to 5 s, still a relatively long time for adults. We administered a brief guessing task (similar to Experiment 3) *prior* to the memory task, to assess adult guessing.

Method

Participants

Participants were 26 University of Delaware undergraduates (16 females) (M = 18.75 years, range: 18–23 years) from the same research pool as in the previous experiments with adults.

Stimuli

Stimuli were the same as in Experiment 4, except that 12 multi-object scene pairs were added for the guessing game task.

Design and procedure

Design and procedure duplicated Experiment 4 except for these three changes: (a) stimulus duration was reduced to 5 s, (b) participants were run in pairs, so instead of spoken responses, they marked their responses on a response sheet (top vs. bottom picture), and (c) participants were administered a 12-item guessing game task after the perceptual matching task.

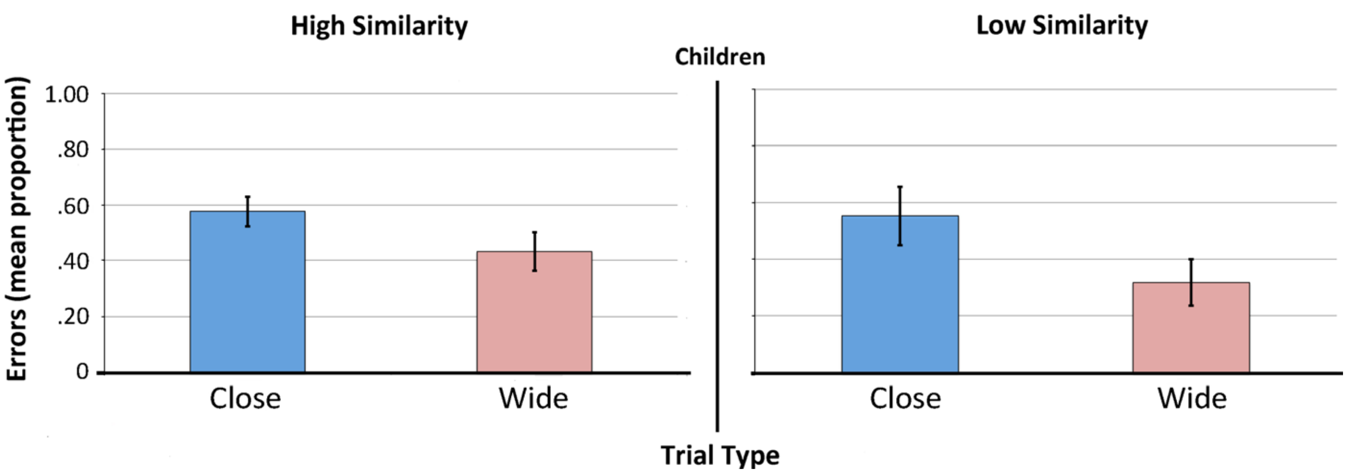

Figure 9 *Children's mean proportion of errors on close trials (close-up was the target) and wide trials (wider-view was the target), as a function of test picture similarity (high vs. low) in Experiment 4. Error bars show the .95 confidence interval around each mean. A greater proportion of errors on close trials indicates BE.*

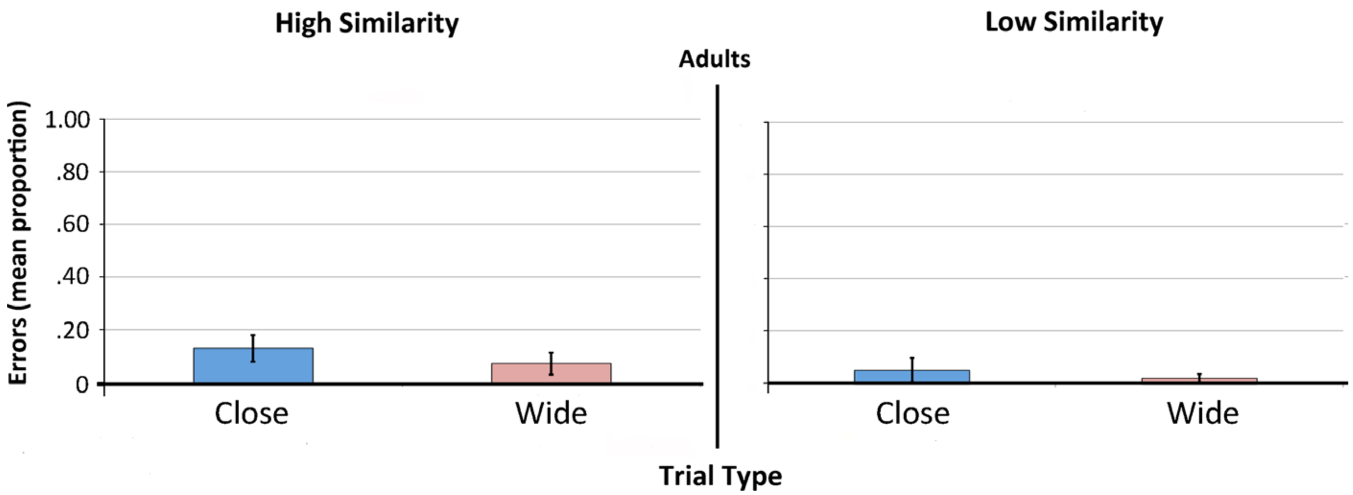

Figure 10 *Adults' mean proportion of errors on close trials (close-up was the target) and wide trials (wider-view was the target), as a function of test picture similarity (high vs. low) for adults (Experiment 5). Error bars show the .95 confidence interval around each mean. A greater proportion of errors on close trials indicates BE.*

Results and discussion

Adults made no errors on the perceptual matching task. In the memory experiment, the proportion of errors as a function of trial type and similarity is shown in Figure 10. A two-way repeated measures ANOVA, trial type (close trials vs. wide trials) × Similarity (high vs. low) showed that the critical response asymmetry approached, but did not reach significance, $F(1, 25) = 3.95$, $p = .058$. Participants made more errors on high-similarity than low-similarity trials, $F(1, 25) = 16.85$, $p < .001$, and there was no trial type × similarity interaction, $F(1, 25) = 1$, $p = .33$. Confidence intervals (Figure 10) revealed a significant number of errors only on the high-similarity trials (confidence intervals excluded 0). Giving the ceiling effect on low-similarity trials, we directly contrasted trial type for the more demanding high-similarity trials with a *t*-test. Here significant boundary extension emerged for the adults, $t(25) = 2.12$, $p < .04$. On the guessing game task, adults exhibited no guessing bias, selecting the wider view on 47% (SD = 16%) of the trials, which did not differ from chance (50%), $t(25) = 0.84$, $p = .41$.

General discussion

Preschool children (4–5 years old) exhibited boundary extension in memory for photographs – they remembered seeing the anticipated continuation of the scene beyond the photograph's boundaries. This constructive error was evident in recall (drawing task: Experiment 1) and in an immediate forced-choice recognition test (Experiments 2 and 4). This occurred in memory for simple close-ups that included one main object (Experiment 2) and for more complex, multi-object views taken from a greater distance (Experiment 4). Under the same presentation conditions, adults also exhibited boundary extension for simple close-ups (Experiments 1 and 2), but *not* for the more distant, complex views (Experiment 4), unless stimulus duration was shortened (Experiment 5), a difference that may reflect developmental differences in source attribution. We will discuss these experiments, focusing on the similarities and differences in children's and adults' performance, in terms of scene construction processes during perception and source attribution decision at retrieval (*multisource model*; Intraub, 2010, 2012; Intraub & Dickinson, 2008)

In Experiment 1, when children drew a photograph from memory, their spatial errors were similar to those reported for older children in prior research (Candel *et al*., 2004; Seamon *et al*., 2002). They reduced the size of the main object (a basketball that in the original photograph filled a majority of the picture space), and increased the background area (the gym floor and wall) creating a more wide-angle view; these spatial changes are consistent with boundary extension. A new control task (the object-drawing task) in which participants drew a named object ('a happy face') ruled out the possibility that smaller objects in children's drawings were caused by an inability (e.g. small hands) or an unwillingness (fear of crossing the boundary lines) to draw a larger object in the response box. Children and adults both drew a larger round object in the object-drawing task than in the scene-memory task. The drawing results were consistent with boundary extension and ruled out some possible drawing artifacts. The critical next step was to seek converging evidence in a test that involved no drawing ability at all.

In Experiment 2, we administered a two-alternative forced-choice test to the same children and adults. The stimulus photograph (either a close-up or a wider view) was rapidly replaced with a test card showing both the close-up and wider-angle version of the scene. There was always one photograph on the test card that was identical to the stimulus view. Participants were asked to point to that photograph. Both age groups exhibited the asymmetric error pattern diagnostic of boundary extension; participants more frequently erred by selecting the wider view (when the stimulus was the close-up) than by selecting the closer view (when the stimulus was the more wide-angle view). Children and adults were sensitive to the subtle spatial differences between test pictures; they made significantly more errors on high-similarity trials (wider views zoomed out 13%) than low-similarity trials (wider views zoomed out 30%).

To determine whether the error asymmetry might have reflected a selection bias favoring wider views, rather than reflecting boundary extension, in Experiment 3, children participated in a guessing game task. They watched an adult confederate study stimulus cards and guessed which view the adult was observing using the same type of forced-choice test cards as in Experiment 2. Children did indeed exhibit a guessing bias, but it in the *opposite* direction. They favored selection of the *closer* view. No evidence of a bias was observed in adult performance on the guessing task (Experiment 5). Thus, if anything, this bias may have caused an *underestimation* of children's boundary extension in Experiment 2.

In Experiment 4, we asked if more complex, multi-object views might overload visual working memory for 4–5-year-olds (Cowan *et al.*, 2010, 2011) or perhaps distract them from attending to the scene as a whole, possibly disrupting scene construction and eliminating boundary extension. However, children's forced-choice performance in Experiment 4 mirrored that observed in memory for simple scenes in Experiment 2. They exhibited the critical response asymmetry, and a brief version of the guessing task replicated the earlier observation (Experiment 3) that their guessing bias ran opposite to boundary extension (favoring close-ups). In spite of increased complexity, children remained sensitive to the subtle spatial differences between high- and low-similarity test pairs, making more errors on high-similarity trials. In contrast, adults in Experiment 4 did *not* exhibit boundary extension, in fact, they rarely erred. This was not due to these stimuli failing to elicit a representation of surrounding space, because the same set elicited boundary extension when stimulus duration was reduced from 15 s to 5 s in Experiment 5. We propose that given the additional time in Experiment 4, adults (but not children) were able to implement strategies that helped minimize source misattribution at test.

In considering the mechanisms underlying performance, we first consider the similarities in performance between groups and then the key differences in performance. With the exception of Experiment 4, participants in both age groups exhibited boundary extension. We suggest that participants treated the 2D photographs as if they were part of a continuous world. Their representation included not only a reflection of the visual information conveyed by the photograph, but also a representation of the expected continuation of the view conveyed by top-down sources of information that 'filled-out' the expected surrounding space. These sources may include: amodal continuation of surfaces beyond the view-boundaries (e.g. McDunn *et al.*, 2014; Fantoni *et al.*, 2008), expectations about layout based on rapid scene classification (Greene & Oliva, 2009), and object-to-context associations (Bar, 2004).

While the photograph is physically present, participants do not confuse ongoing visual-sensory information with top-down sources of information. The photograph's boundaries can be directly observed. However, when the photograph is gone, the remembered multisource representation does not include tags that specify the original source of information at each spatial location. According to the multisource model, at test, when participants attempted to remember what they actually *saw*, they engaged in *source monitoring* (Johnson *et al.*, 1993), evaluating the attributes of the remembered information to decide how much of their multisource representation was sufficiently detailed (and percept-like) to be attributed to the studied photograph. Misattribution of constructed information from beyond the boundaries of the photograph to having been seen constitutes boundary extension.

Children exhibited robust boundary extension for the more distant and complex views presented in Experiment 4. Inspection of the graphs shows that performance was remarkably similar to that in Experiment 2. In contrast, adults rarely made errors. We suggest that this difference is likely due to differences in source monitoring. To explain this, it is important to note that for adults it has been well established that boundary extension is greatest for tight close-ups and decreases for more wide-angle views (see Hubbard *et al.*, 2010; Intraub, 2002, for reviews). The difference in the proportion of boundary extension errors for adults in Experiments 2 and 5 (in spite of duration being reduced in the latter) is consistent with this observation. Close-ups appear to elicit a strong sense of expected surrounding space, making boundary extension difficult for adults to overcome, even when they are forewarned (Gagnier, Dickinson & Intraub, 2013; Intraub & Bodamer, 1993). In the current experiments, adults' strategies (e.g. allocation of spatial attention, ancillary verbal descriptions) were not sufficient to eliminate source misattribution for tight close-ups (Experiment 2), but were sufficient to prevent consistent source errors for the more wide-angle views (Experiment 4) unless the time to undertake these cognitive processes was reduced (Experiment 5).

The notion that children might be less adept in making source attribution decisions in general is supported by developmental studies of source monitoring. Research suggests improvement in source monitoring ability between the ages of 3 years and at least 8 years of age (e.g. Foley & Johnson, 1985; Lindsay, 2008; Sluzenski, Newcombe & Ottinger, 2004; Sussman, 2001). The most consistent evidence for a developmental trajectory come from studies requiring participants to distinguish information that had been perceived from self-generated information (as in boundary extension). This is in contrast to distinguishing between two different perceptual sources (Lindsay, 2008; also see Gopnik & Graf, 1988; Woolley & Bruell, 1996, for a discussion of the effects of task difficulty on age-related differences).

Finally, in terms of methodology, we were successful in developing a boundary extension test that is appropriate for 4–5-year-old children, and that does not involve drawing ability. The shift from drawing to recognition memory allows for a much more rapid test (as compared with drawings that take minutes to complete), and for a much wider range of picture types, including relatively complex stimuli (Experiments 4 and 5). Because it is a memory-matching task, this method may be suitable for a wide range of ages, including younger children (e.g. 3 years of age; who did not fare well on Liben's, 2003, photographic literacy task), and also may provide a means for studying boundary extension in children with developmental disorders associated with spatial cognition, such as Williams syndrome (Landau & Hoffman, 2012) or delayed hippocampal development, such as Down syndrome (Edgin, 2013).

In conclusion, our results show that young children (4–5 years old) perceive photographs as views of the world, and automatically construct a representation of surrounding space that goes beyond the visual-sensory information. Anticipatory spatial representation beyond the boundaries of a view may play an important role in interacting with and navigating through a world that we can only perceive a part at a time.

Acknowledgements

The authors thank research assistants Donna Muccio, Danielle DeRiggi, Kimberly Swezey, Alexandria Brogan, and Danielle Gilley. We are grateful to Bianca Graves, Research and Clinical Placement Coordinator, University of Delaware Early Learning Center, for her invaluable support. We thank Matt Doran and Steven Beighley for their helpful suggestions during the course of the study; and Paul Quinn, Jamie Edgin, Steven Beighley, Amanda Ly and Elizabeth Vlachos for their insightful comments on earlier versions of the manuscript.

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Received: 27 August 2015
Accepted: 23 March 2016