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Young Children's Use of Surface and Object Information in Drawings of Everyday Scenes

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Pictorial symbols such as photographs, drawings, and maps are ubiquitous in modern cultures. Nevertheless, it remains unclear how children relate these symbols to the scenes that they represent. The present work investigates 4-year-old children's (N = 144) sensitivity to extended surface layouts and objects when using drawings of a room to find locations in that room. Children used either extended surfaces or objects when interpreting drawings, but they did not combine these two types of information to disambiguate target locations. Moreover, children's evaluations of drawings depicting surfaces or objects did not align with their use of such information in those drawings. These findings suggest that pictures of all kinds serve as media in which children deploy symbolic spatial skills flexibly and automatically.

Spatial symbols, such as photographs, drawings, and maps, represent the distances, directions, lengths, and angles of both extended surface layouts and small-scale objects. Such symbols are meaningful to infants, young children, and adults from many cultures (Dehaene, Izard, Pica, & Spelke, 2006; DeLoache, 1987, 1991, 2004; Shinskey & Jachens, 2014; Winkler-Rhoades, Carey, & Spelke, 2013). Most studies of children's interpretation of spatial symbols have focused on their implicit understanding that pictures represent scenes and objects and thus cannot be moved through or acted upon (e.g., DeLoache, 2004; Preissler & Carey, 2004). However, recognizing that something is a symbol is only one step toward its use. Little is yet known about how children relate the geometry in pictures to the scenes and objects that these pictures represent. In this study, we ask what information children use and what information they think is useful when interpreting line drawings of a typical furnished room. We thus evaluate how symbol reading might engage those sensitivities that form the foundation both of our everyday interactions with the spatial world and of our more abstract geometric reasoning.

Human sensitivity to shape information in edge-based perspectival line drawings of scenes and objects is afforded by basic properties of our visual system. By capturing the occluding and nonoccluding edges of the surfaces and objects in a scene, but not the brightness edges, such line drawings present the depicted world in a highly interpretable fashion (Cole et al., 2009; Gibson, 1971; Hubel & Weisel, 1962; Hubel & Wiesel, 1968; Kennedy & Ross, 1975; Olshausen & Field, 1996; Sayim & Cavanagh, 2011; von der Heydt, Peterhans, & Baumgartner, 1984). Although the capacity to recognize two-dimensional (2D) shape information in such drawings is present in the visual systems of other animals (Kirkpatrick-Steger, Wasserman, & Biederman, 1998), 1.5- to 2-year-old children go beyond detecting the basic similarities between pictures and their referents, and begin to view pictures as symbols that provide information about their referents (Preissler & Carey, 2004). Indeed, in a search paradigm pioneered by DeLoache (1987, 1991), 2.5-year-old children were able to retrieve a hidden doll in a room when given only a picture of its hiding location (DeLoache, 2004; see also Winkler-Rhoades et al., 2013; Uttal & Yuan, 2014).

Studies have begun to examine what geometric information children use when navigating by such spatial symbols. For example, 4-year-old children

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use the length relations defining locations in an environment when navigating by a symbolic map (Huttenlocher, Newcombe, & Vasilyeva, 1999; Izard, O'Donnell, & Spelke, 2014) but not when navigating without a map (Lee, Sovrano, & Spelke, 2012). Moreover, 4-year-old children use the relative sizes of angles to navigate by overhead maps specifying locations in a fragmented three-dimensional (3D) triangular environment in which only corner angles of different sizes are present (Dillon, Huang, & Spelke, 2013; Izard et al., 2014), but 2-year-old children ignore angle information when navigating without a map in a 3D fragmented rhomboidal environment (Hupbach & Nadel, 2005; Lee et al., 2012). Four-year-old children extract and use distance and directional information in 2D forms when those forms are presented as symbolic drawings of a 3D room (Dillon & Spelke, 2015), but even older children often fail to use directional information when differentiating between nonsymbolic 2D visual forms and their mirror images over changes in orientation (Dehaene et al., 2006; Izard & Spelke, 2009). Spatial symbols thus permit children to access geometric information more flexibly than they otherwise would when navigating environments or recognizing objects without symbols.

Despite this flexibility, young children's use of spatial symbols suffers from serious limitations when compared to that of adults. For example, Dillon and Spelke (2015) investigated 4-year-old children's use of geometry when interpreting highly realistic perspectival line drawings and photographs of an empty 3D room and a 3D Lego object with the same metric and landmark properties as the room. Despite being presented with canonical viewpoints in the pictures, children interpreted pictures using different geometric information depending on whether the pictures were presented in the context of the room or the object. In the former case, children recruited representations of absolute distance and direction used for navigation, and in the latter case, they recruited representations of relative length and angle used for shape analysis. With the pictures of the room, children located targets more successfully at corners, and they erred by ignoring the shapes of surface markings and landmarks. With the pictures of the object, in contrast, children located targets more successfully near landmarks, and they erred by ignoring the directional relations that differentiated a target to the left of a landmark from one to its right. In addition, children's picture-guided search of the room was predicted by their scores on a nonsymbolic navigation task, whereas their picture-guided search of the object was predicted by their scores on a nonsymbolic shape analysis task. Similar findings were obtained in experiments in which children navigated by overhead maps (e.g., Dillon et al., 2013; Huang & Spelke, 2015): With maps as with perspectival pictures, children flexibly extracted geometric information from the spatial symbols, but they used only one set of geometric representations at a time, either those relevant to navigating through a scene or those relevant to recognizing objects, depending on the context in which the symbols were presented.

Can young children nevertheless use spatial symbols to relate large extended surfaces to small-scale landmark objects during a search task? Surfaces and objects occur together in scenes and in pictures of scenes, but their shape properties are encoded by distinct regions of the brain (e.g., Doeller, King, & Burgess, 2008), and they are dissociated behaviorally in preschool-aged children and nonhuman animals (e.g., Cheng, 1986; Hermer & Spelke, 1996). A series of studies on adults' and children's navigation without symbols has shown that there is at least one uniquely human capacity that is effective at promoting the integration of surface and object information: language. Adults are thought to engage linguistic processes when they spontaneously combine geometric properties of the extended surface layout with landmarks, that is, when they reorient themselves in a room with one wall that is a different color from the others or has an object in front of it. Integrating surface geometry with landmark information during this search task emerges at about 6 years of age, correlates with the use of the words "left" and "right" during referential communication (Hermer-Vazquez, Moffet, & Munkholm, 2001) and declines in adults during a verbal shadowing task (Hermer-Vazquez, Spelke, & Katsnelson, 1999) unless adults are alerted to its relevance (Ratliff & Newcombe, 2008). Finally, even 4-year-old children can distinguish targets using the combination of extended surface geometry and landmarks when language is used to highlight the relevant landmark information (e.g., "I'm hiding the sticker at the colored wall"; Shusterman, Lee, & Spelke, 2011).

These findings raise the question of whether nonlinguistic spatial symbols, such as maps or pictures, would also lead 4-year-old children to relate extended surface information to landmark objects when they navigate. Previous studies investigating this question found no evidence for this ability (as described above), but those studies presented children with pictures depicting the world from an

unfamiliar perspective (e.g., an overhead view in a map) or depicting an unusual environment or object (e.g., a fragmented or empty room, or an arbitrarily constructed Lego object). In contrast, children interact with the world from their eye-level perspective rather than from above, and these perspectives typically incorporate information about both extended surfaces and objects. Preschool children are more successful at finding the geometric correspondences between maps and environments when the environments are familiar and are presented from a familiar perspective (Liben & Yekel, 1996). In creating their own maps, moreover, children in kindergarten tend to use eye-level perspectives, whereas older children tend to adopt overhead views (Liben & Downs, 1994). Even adults are better at interpreting line drawings and photographs that present objects from familiar, canonical viewpoints (Tarr & Pinker, 1989; see also Landau, Hoffman, & Kurz, 2006), suggesting that visual experience plays a role in extracting relevant shape properties from drawings.

Children might also form more integrated interpretations of pictures depicting surfaces and objects from familiar perspectives because the pictures that they typically encounter, for example, in storybooks, often include both surface and object information together. A survey of prize-winning children's books (winners of the Caldecott Medal, given each year by the American Library Association to the illustrator of the most distinguished picture book for children) revealed that the vast majority of pictures in these books (90.3%) depict both surfaces and objects together, whereas only 2.5% of pictures include just surface information, and only 7.2% of pictures include just object information (see Supporting Information for more information). Preschool children might build on their experiences with such pictures to form more integrated representations of the scenes that they depict.

Children's typical interactions with canonical scenes and pictures of surface layouts and objects together, presenting perceptually familiar viewpoints with high fidelity, may therefore elicit better performance in a symbolic spatial task (Callaghan, 2000; Ganea, Pickard, & DeLoache, 2008; Simcock & DeLoache, 2006, 2008; Uttal & Yuan, 2014; Walker, Walker, & Ganea, 2013) and provide evidence for a more integrated understanding of layout and object geometry than has been observed in previous studies. To investigate this possibility, we compared children's ability to find locations in a room using information in three different types of drawings: drawings depicting only a room's extended surfaces, drawings depicting only the objects in the room, and drawings depicting the room's surfaces and objects together, all with realistic renderings of occlusion. If children can integrate information about surfaces and objects in drawings, then they should show enhanced abilities to interpret pictures displaying both the extended surface layout and the objects in that layout.

Finally, although prior studies have shown children's flexible use of geometry when reading spatial symbols, no studies have explored children's awareness of the geometric properties of pictures that make them informative representations of scenes. When looking at a picture of a room, children might recognize that extended surface information is more informative about locations that are specified by the extended surfaces in the 3D layout and that landmark shape information is more informative about the locations in the room near landmark features. Children might then selectively attend to the relevant information in the symbol or in the environment to complete the picture-interpretation task.

Alternatively, children might extract geometric information from spatial symbols automatically whenever these symbols are presented in a particular 3D context and without any awareness of the information that they are using. When a drawing is meant to represent an extended surface layout, for example, children might automatically extract the distance and directional information that guides their navigation in such a layout; when a drawing represents one or more objects, children might automatically extract the relative length and angle information that guides object recognition and categorization. Such automatic responses have been observed in adults' use of shape information in everyday nonsymbolic acts of navigation and object recognition (e.g., Doeller et al., 2008).

In order to investigate young children's sensitivity to the geometry of extended surface layouts and the objects in those layouts when interpreting pictures, we asked 4-year-old children to locate target disks in a room using line drawings of that room (Experiment 1) and to evaluate which of two line drawings better indicated a specific target location (Experiment 2). In both experiments, we manipulated the information in the drawings, showing children either extended surface information only, object information only, or (in Experiment 1) both surface and object information together. We also manipulated the location of the target, which was either in a corner of the depicted room or near an

object in the room. First, we evaluated whether children performed better when given pictures that had both extended surface information and object information together, compared to just the one type of information that better specified each target location. Then, we evaluated whether children correctly judged which pictures would be most useful for finding different locations in the room.

General Methods

Displays

Both experiments took place in a 5.44 × 2.51-m laboratory testing room, which had a door on one short wall, a window on the opposite short wall, and a large column against one long wall. The room was furnished with two stacking chairs, one swivel chair, one storage bin, one trashcan, and one child-sized table with two child-sized chairs. The two stacking chairs were the same model, but one was placed with its back to the long wall with the column, and the other was placed with its back to the short wall with the window. The storage bin and the trashcan had a similar shape, but the storage bin was bigger. The bin was placed to the left of the stacking chair by the window, and the trashcan was placed to the left of the stacking chair by the column. The child-sized table was placed toward the window side of the room with the matching chairs at its opposite corners. The swivel chair was placed in the corner or the room to the right of the door. This setup resulted in four objects located on the door side of the room and four objects located on the window side of the room (Figure 1).

Twelve bright red rubber disks (10 cm in diameter and 0.5 cm in thickness; six on the door side of the room and six on the window side of the room) were placed on the floor to serve as possible response locations. The floor was gray, providing a strong contrast to the red disks, and there were no other red objects in the room. Eight of the response locations were used as targets in the experiments (four on the door side of the room and four on the window side of the room). Four targets were located at the room's corners (i.e., the junctions of the room's extended surfaces), and four targets were located next to objects in the room. Nontarget disks were placed at locations in the room that bore similar relations to the room features (Figure 1).

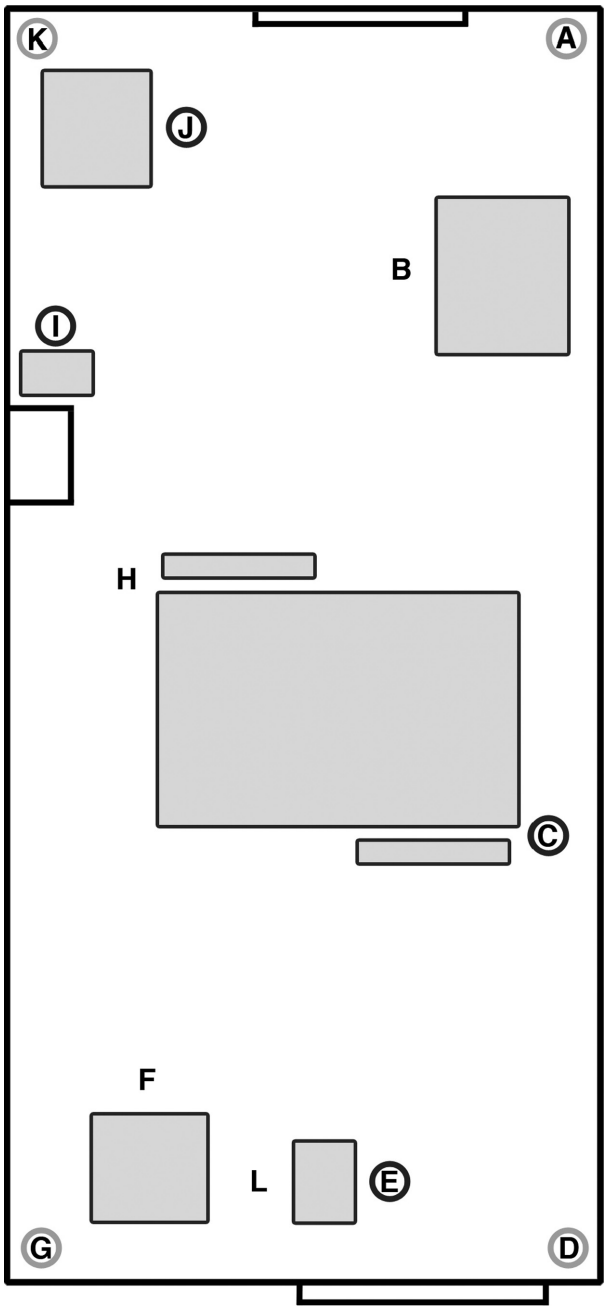

Figure 1. Overhead schematic view of the room, objects, and target locations in the line drawing interpretation and evaluation tasks. The room is drawn to scale and the diagram indicates the location of the door (top) and window (bottom) on opposing walls. The column against the wall of the room is indicated on the left of the diagram by a white box with a black outline. Objects in the room are indicated by gray rectangular shapes. Possible response locations are labeled by letters (A–L). A light gray circle around a letter indicates that it served as a corner target, and a dark gray circle around a letter indicates that it served as an object target.

Eight color photographs were taken of the room from eight different perspectives, 97 cm off the ground (the height of a typical 4-year-old child). Three sets of eight line drawings were created by tracing the edges of occluding and nonoccluding surfaces in each photograph (Figure 2). In the first set of drawings, only the lines indicating the room's extended surfaces were

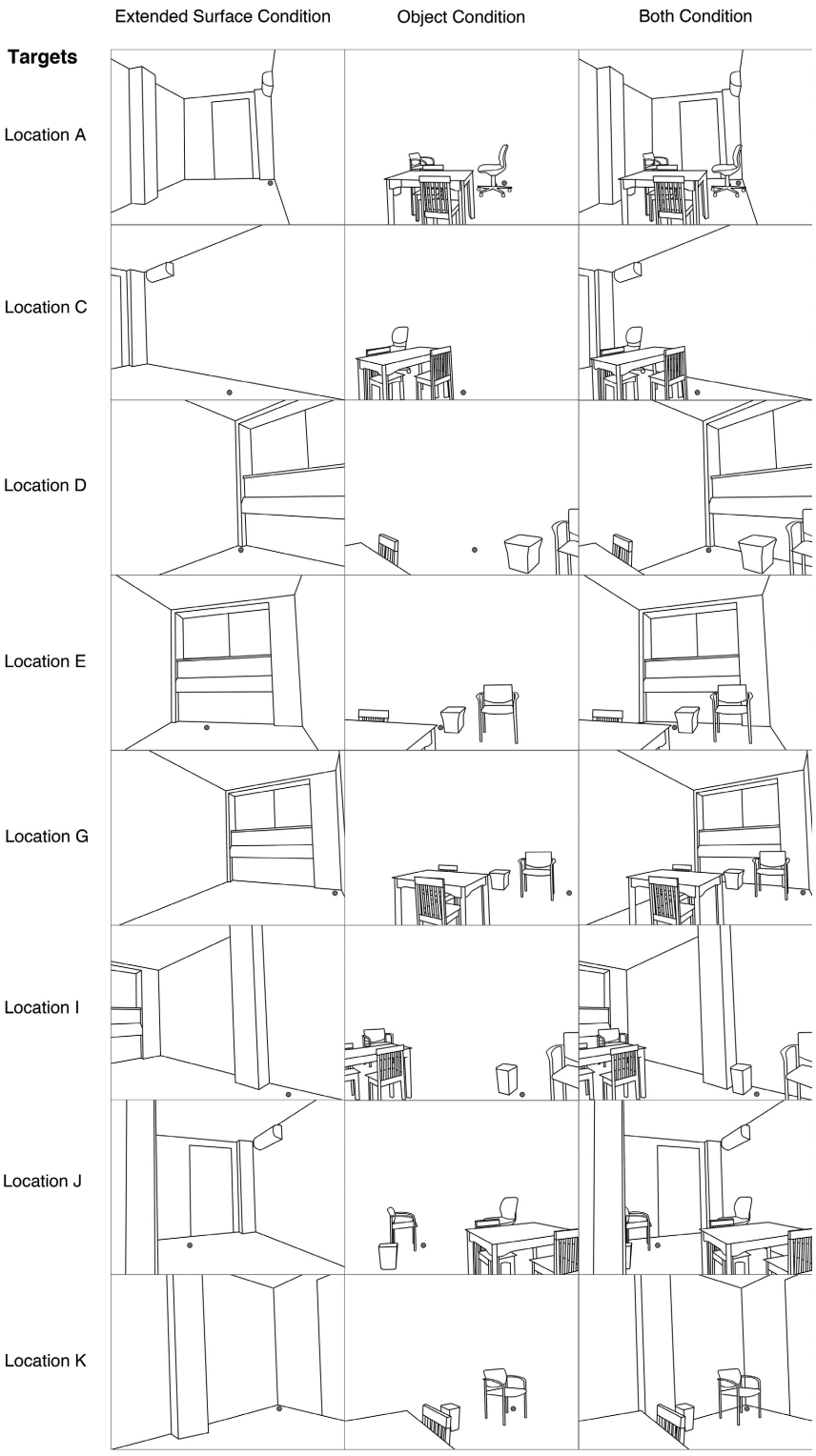

Figure 2. Line drawings depicting each of the eight target locations used in the interpretation and evaluation tasks. The left column presents the extended surface drawings, depicting only the walls, floor, ceiling, outline of the door and window frames, and the air conditioner. The center column presents the object drawings, depicting only the objects in the room. The right column presents the drawings depicting both the extended surfaces and the objects together. One dot (here, in gray) in each picture indicates a target location in the room. Locations A, D, G, and K are all corner targets (in which the targets are directly at the junctions of two extended surfaces), and Locations C, E, I, and J are all targets near objects (in which the targets are right next to objects).

depicted, including its walls, floor, ceiling, outline of the door and window frames, and the wall-mounted air conditioner, all presented as complete lines as if the room contained no occluding objects. In the second set of drawings, only the lines indicating the shapes of the objects were depicted, all presented as complete lines except where one object was partly occluded by another. Although these two sets of drawings depicted the room from canonical viewpoints, their depiction of only limited information was likely highly unusual to children, as children's typical eye-level views often present extended surface and object information together, and the typical pictures that they encounter include both surface and object information together. The third set of drawings were thus designed to be not only accurate in their rendering of the room but also more familiar: Lines indicated the room's extended surfaces and its objects together, with accurate renderings of occlusion. A single red dot—indicating one of the target disks in the room and consistent across the corresponding drawings in the three sets—was added to each drawing to indicate the target location (Figure 2).

Experiment 1

Overview

In Experiment 1, children completed a line drawing interpretation task, in which they were shown drawings of the room and were asked to place a stuffed animal at locations in the room indicated by the red dot that appeared in each drawing. One group of children saw depictions of the room's extended surfaces, one group of children saw depictions of the room's objects, and one group of children saw depictions of both surfaces and objects together. We examined whether children's performance at different target locations differed for the different types of drawings. We then asked whether the children who were presented with the highly typical drawings of surfaces and objects together performed better than those who were shown the less familiar drawings presenting only the extended surfaces or only the objects. If children use only extended surface information or only object information, albeit in a flexible fashion, then they may not benefit from the simultaneous presence of both surfaces and objects in pictures.

Participants

One-hundred and forty-four 4-year-old children (72 females; M_{age} = 4;5, range = 4;0–4;11), participated in a line drawing interpretation task. Children were recruited by mail and by posted flyers in a middle-class area in the northeast United States. Most children were Caucasian. Children were randomly assigned to see drawings of extended surfaces only (N = 48), objects only (N = 48), or both types of information together (N = 48). Data were collected from January 2013 through January 2014.

Procedure

After children entered the room, they were acclimated to it by standing in the center and turning around to point to each of the four walls, each of the four corners, and each of the eight objects. Before the test trials, two practice trials were presented, using color rather than geometry to specify a target location: Children were asked to put a small stuffed animal on either a blue or green disk in the center of the room after the experimenter pointed to either a blue or green circle in the center of an otherwise blank laminated sheet of paper. During the test trials, children stood in the center of the room with the experimenter, were shown line drawings of the room belonging to only one set (extended surfaces only, objects only, or both surfaces and objects), and were asked to place a stuffed animal in the room on the locations indicated by the red dots in the drawings. Before the start of the next trial, children picked up the animal and returned to the center of the room. Six of the eight drawings were presented to each child, three drawings depicting different targets located in the corners of the room and three drawings depicting different targets located near objects in the room. Picture presentation order, facing direction (to one of the room's four walls), and the choice of six of the eight drawings were all counterbalanced across children. Each of the eight target locations was assessed 35, 36, or 37 times (depending on the target location) for each drawing type. On every trial, the response location was recorded. Because there were 12 possible response locations, chance was 1/12 (0.08). Three outcome variables were calculated for each child: the total proportion of correct placements (of the six), the proportion of correct placements for the targets in the corners of the room (of the three), and the proportion of correct placements for the targets near objects in the room (of the three).

Results

We first investigated whether the children who navigated a room using pictures that displayed

both extended surface and object information together performed better at placing the animal in the indicated locations than children who navigated by pictures displaying only one type of information. Second, we examined whether success differed by target location in the two groups of children who saw only one type of information in pictures: Did children who used pictures with extended surface information perform better at target locations in corners while children who used pictures with object information performed better at target locations near objects? Finally, we revisited children's performance in the condition presenting both types of information to ask whether they interpreted pictures by considering extended surface information and object information together, or instead by switching flexibly between the two types of information, depending on the target location. With these analyses, we begin to evaluate whether familiar pictures of scenes, depicting both extended surfaces and objects, allow young children to relate layout information to landmark objects.

We first performed a two-way analysis of variance (ANOVA) testing whether children's proportion of correct responding was affected by sex and drawing type, which were included as between-participants variables. The analysis revealed no main effect of sex, $F(1, 138) = 0.07$, $p = .794$, $\eta_p^2 = .00$ (responses were thus collapsed across sex for all further analyses), but a significant effect of drawing type, $F(2, 138) = 3.91$, $p = .022$, $\eta_p^2 = .05$. Post hoc, one-sided Dunnett's tests evaluated the advantage of having both types of information in drawings versus only one type and determined that children performed better in the both condition ($M = .45$, $SD = 0.21$) compared to the extended surface ($M = .36$, $SD = 0.22$), $p = .037$, or object conditions ($M = .34$, $SD = 0.19$), $p = .009$. Children presented with pictures of extended surfaces and objects together performed better overall than children presented with only one type of information in pictures.

We next tested whether children's proportion of correct responding at corner and object target locations was affected by drawing type using a 2×2 mixed-factor ANOVA, with target location (at a corner or at a landmark object) as the within-participants variable and drawing type (surfaces only or objects only) as the between-participants variable. The analysis revealed no main effects but a significant Target Location $\times$ Drawing Type interaction, $F(1, 94) = 6.78$, $p = .011$, $\eta_p^2 = .07$ (Figure 3). To better understand the nature of this interaction, we determined the simple effects of each variable using

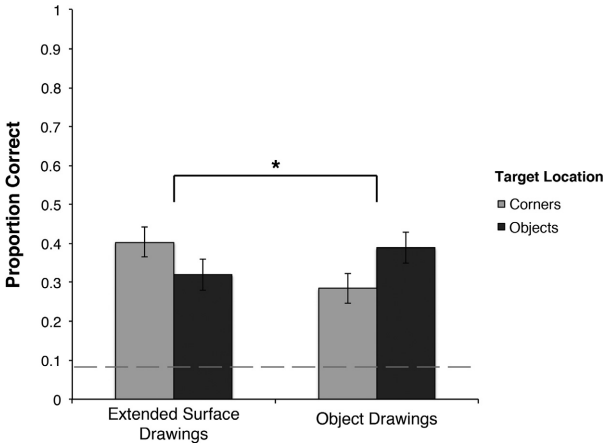

Figure 3. Children's performance on the interpretation task at targets located in the corners of the room or near objects in the room when they were asked to use either extended surface information or object information in drawings. The gray dotted line at 0.08 indicates chance performance.* $p < .05$

orthogonal contrasts. Children who saw drawings depicting only the room's extended surfaces were marginally more successful at finding corner targets than those who saw drawings of just the objects in the room, $t(94) = 1.64$, $p = .105$, Cohen's $d = .34$, and those who saw drawings of objects were significantly more successful at finding targets near objects than those who saw drawings of extended surfaces, $t(94) = -2.05$, $p = .044$, Cohen's $d = .42$.

Given these moderate differences in children's use of each type of information in drawings depending on the location of the target, we revisited children's performance in the condition presenting both surfaces and objects together to determine whether their greater performance overall could be explained by a flexible use of only one type of information at a time, as has been shown in other studies. Specifically, did children use depictions of extended surfaces and objects together so as to disambiguate between a corner target with a chair on its left versus on its right or between an object target with a corner on its left versus on its right? Or, did children use only one type of information (the extended surfaces or the objects) to find each target location in the room, flexibly selecting the more informative type of information on each trial? To distinguish between these possibilities, we compared the responses of children in the condition with both types of information to the responses of children in the condition presenting the one type of information that yielded higher performance at each target location.

At none of the eight target locations did children perform better in the condition with both types of information than in the better of the two conditions with only one type of information, *p*s > .950, Bonferroni corrected (Figure 4A). Moreover, children's average performance in the condition with both types of information was not superior to their average performance with the drawings presenting the one type of information that was more informative for each target location, *p*s = 1.000 (Figure 4B). These findings suggest that children in the condition with both types of information did not combine information about surfaces and objects but rather focused on the more informative type of spatial information for each particular target location.

This failure to find a difference between children's performance in the condition with both types of information and children's performance in the better of the two conditions presenting only one type of information does not allow us, however, to positively conclude a lack of difference. To provide evidence for such a lack of difference, we calculated the average 95% confidence intervals, in standard deviations, above and below which it was unlikely that the addition of the missing information to the two drawing types presenting only one type of information would improve or worsen performance. The addition of the missing information was unlikely to improve performance by more than 0.39 *SD*, and it was just as likely to worsen performance by the same factor, −0.39 *SD*. These values contrast with the range of improvement offered by the more relevant, compared to less relevant, information, where the bounds of the 95% confidence

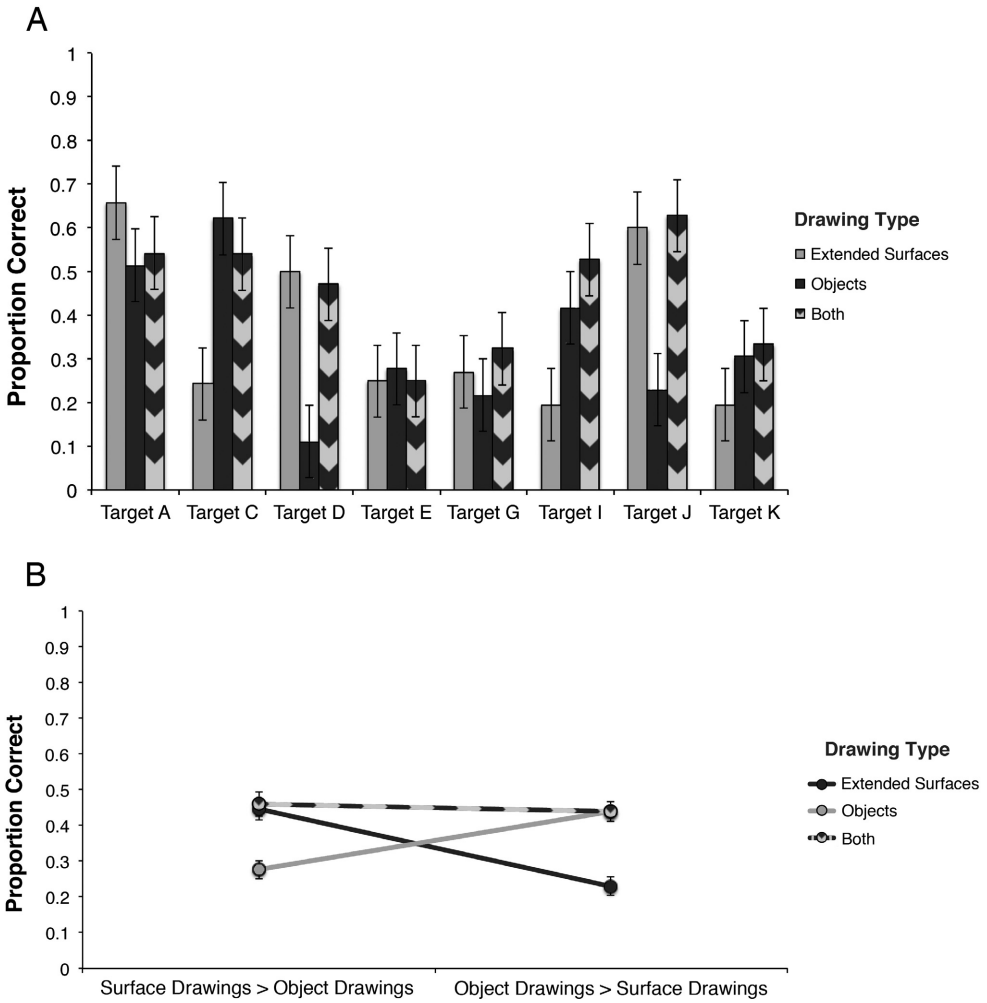

Figure 4. (A) Children's performance on the interpretation task at each target location using extended surface drawings, object drawings, and both drawings, the last of which depicted both extended surface and object information together. (B) Children's average performance at targets in which performance was better with the surface-only drawings or object-only drawings broken down by the three drawing types.

interval indicate improvement only, ranging from 0.28 to 1.05 *SD*. These results more strongly indicate that children's overall success in interpreting drawings that depicted both extended surfaces and objects together likely reflected their ability to flexibly use one type of information or another in the drawings, rather than their ability to combine depicted extended surfaces and objects to form integrated representations of target locations.

Discussion

When presented with both types of information in drawings, children performed better overall than when presented with only one type of information. Moreover, children's success at different target locations was affected by the information in the drawings. Children were moderately more successful with drawings that depicted extended surface information when targets were located at the corners of the room and moderately more successful with object drawings when targets were located next to objects, although the *p* value for the former contrast fell short of significance. As such, children's greater success in the condition with both types of information could be explained by a focus on only one type of information at a time: When presented with the more informative pictures containing both extended surface and object information together, children showed no additional advantage of combining this information beyond the performance they achieved with extended surface or object information alone at any particular target location.

Could children's failure to benefit from both surfaces and objects together in pictures be explained by information overload? In tasks that require card sorting by one type of information when multiple types are presented, 5-year-old children perform less well compared to older children when presented with too much information (e.g., Shepp, Barrett, & Kolbet, 1987). In these cases, however, the additional information was either orthogonal to the information on which children needed to focus, and was therefore distracting, or was viewed by younger children as integrated with the other information presented, such that selective attention to that particular type of information was not possible. In the present study, however, the additional information in pictures that depicted both surfaces and objects together was informative rather than orthogonal because it further disambiguated the target locations. Moreover, an abundance of research has shown that surfaces and objects are treated as separate spatial features not only by human children (e.g., Lee et al., 2012) but also by adults and animals (e.g., Doeller et al., 2008). Finally, investigating the effects of language on children's search behavior reveals that when 4-year-old children are given additional relevant linguistic information about landmarks during a navigation task, they incorporate this information into their representation of the layout and search more accurately (Shusterman et al., 2011). Thus, we do not believe that children's failure to show enhanced performance in the condition with both types of information can be explained by there being too much information in the pictures.

Could children's failure to benefit from pictures in the both condition stem from those pictures presenting more occlusion (i.e., where objects stood in front of surfaces)? We believe such occlusion is also unlikely to account for the lack of benefit in children's responses. Even infants perceive extended surfaces and objects as continuing behind occluders (e.g., Kellman & Spelke, 1983; Termine, Hrynick, Kestenbaum, Gleitman, & Spelke, 1987). Moreover, if the natural patterns of occlusion in pictures of furnished rooms cause problems for young children, it is unlikely that these kinds of pictures would be so prevalent in the most popular and valued picture books for young children (see Supporting Information).

We thus conclude that the children in the interpretation task of Experiment 1, who saw pictures with both extended surfaces and objects together, performed no better on each target location compared to children who saw the one, more informative type of information because these children failed to integrate the two types of spatial information. Even when presented with highly realistic and typical spatial symbols, young children show limited ability to combine information about surfaces and objects to enhance their symbol-driven navigation.

Despite this limitation, different groups of children relied on depicted surfaces or objects with similar overall success. The line drawing evaluation task in Experiment 2 (below) begins to investigate whether this flexibility is strategic or automatic by probing whether children recognize, when reading spatial symbols, that depictions of surfaces are more informative in specifying locations at the corners of extended surfaces and that depictions of objects are more informative in specifying locations near objects. This recognition could support children's differential success at corner and object targets. On the other hand, if children do not recognize the relative importance of extended surface or object information in specifying target locations, then their selective attention to depicted surfaces or objects may happen more automatically.

Experiment 2

Overview

In Experiment 2, children completed a line drawing evaluation task, in which they were asked which of two drawings—one depicting just the extended surfaces of the room and one depicting just the objects in the room (Figure 2)—they thought better indicated a target location either at a corner or near an object in the room (Figure 1). The purpose of this task was to examine what information children felt was important in relating a drawing to the environment it represented. If spatial symbols allow children to identify the relevant information for specifying particular target locations, then they should indicate that extended surface drawings are better depictions of targets located at room corners and that object drawings are better depictions of targets located next to objects. In contrast, if children engage extended surface and object information during symbolic spatial tasks more automatically, then they may not be aware of the information in pictures that they use to find different target locations.

Participants

The first 96 children (49 female, M_{age} = 4;5, range = 4;0–4;11) who participated in the line drawing interpretation task (32 from each of the three drawing-type conditions) also participated in a line drawing evaluation task. Forty-eight of these children completed the interpretation task followed by the evaluation task, and 48 completed these tasks in the opposite order.

Procedure

Before the test trials, two practice trials were presented, using color rather than geometry: Children were shown one blue and one green disk in the center of the room and then were shown two laminated sheets of paper, one depicting blue and green circles and the other depicting purple and pink circles. Children were asked, "Which is a better picture of these two spots in the room; Which picture helps us find these spots better?" Test trials consisted of the two target locations that the child was not tested on in the line drawing interpretation task. Children were shown two drawings of each of these locations, one from the set depicting only the room's extended surfaces and one from the set depicting only the objects in the room (Figure 2). For each child, the extended surface drawing was presented on the left for one trial and on the right for the other trial. The presentation order, facing direction (to one of the room's two walls that allowed the target location to be in full view), and the order of the left/right positions of the drawing types were counterbalanced across children. Using the same language as in the practice trial, every child was asked to evaluate one pair of drawings depicting a location in a corner of the room and one pair of drawings depicting a location near an object in the room.

Results

The first set of analyses investigated whether children's evaluation of pictures mirrored their interpretation of pictures in the task of Experiment 1: Do children think that drawings of extended surfaces are more informative depictions of target locations in the corners of the room and drawings of objects are more informative depictions of target locations near objects in the room (Figure 3)? Because these 96 children completed the tasks in both experiments, the second set of analyses tested for relations between children's interpretation of pictures in Experiment 1 and their evaluation of pictures in Experiment 2. We first test for order effects between the two tasks, and then we analyze the correlations between performance on these tasks across children. Such correlations would suggest that the interpretation and evaluation of the picture geometry are related, even if children's explicit judgments do not reveal that relation.

Preliminary analyses showed no significant differences between male and female children in their evaluation of whether extended surface drawings or object drawings are better depictions of targets in the room, $t(94) = 0.76$, $p = .450$, Cohen's $d = .16$. Responses were thus collapsed across sex for all further analyses.

We performed a 2 (target location—at a corner or near an object) × 2 (drawing type—surfaces only or objects only) ANOVA on children's evaluations of the drawings. In contrast to the findings for the interpretation task, we found a main effect of drawing type: Children thought that drawings of objects were more informative than drawings of surfaces, $F(1, 95) = 13.13$, $p < .001$, $\eta_p^2 = .12$ (Figure 5). We also found no interaction between drawing type and target location, $F(1, 95) = 1.70$, $p = .196$, $\eta_p^2 = .02$: Children thought that object drawings were more informative regardless of whether they depicted target locations in corners or near objects.

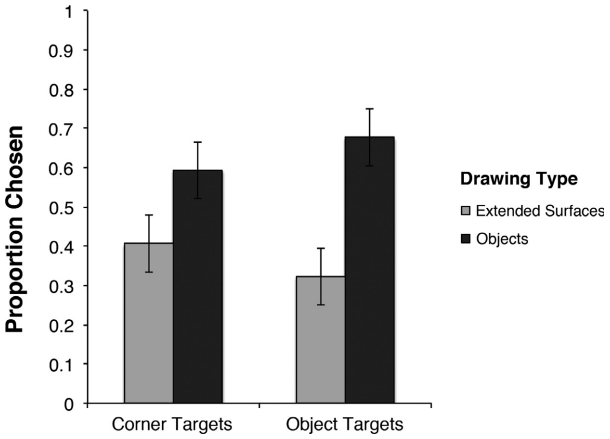

Figure 5. Children's performance on the evaluation task, where they were asked to judge whether extended surface information or object information in drawings better indicated targets located either in the corners of the room or next to objects in the room.

We next tested for implicit relations between children's performance in the interpretation and evaluation tasks by evaluating whether children's performance on the interpretation task of Experiment 1 was affected by whether they completed that task before or after the evaluation task of Experiment 2. A 2 (task order) × 3 (drawing type) × 2 (target location) mixed-factor ANOVA revealed no significant main effect of task order (interpretation task first: $M = .37$; evaluation task first: $M = .32$), $F(1, 90) = 0.81$, $p = .372$, $\eta_p^2 = .01$, no Task Order × Target Location interaction, $F(1, 90) = 2.65$, $p = .107$, $\eta_p^2 = .03$, no Task Order × Drawing Type interaction, $F(2, 90) = 1.85$, $p = .164$, $\eta_p^2 = .04$, and no three-way interaction among these factors, $F(2, 90) = 1.24$, $p = .295$, $\eta_p^2 = .03$. Thus, children who evaluated the pictures before using them to find target locations in the room performed no better at finding those locations than did other children. Asking children about the pictures did not enhance their strategic use of the information that the pictures presented.

A second ANOVA with the same structure tested whether there was any effect of task order on children's responding at the two types of target locations in the evaluation task of Experiment 2. For this analysis, children's responses on the evaluation task were scored as the proportion of choosing the drawing of extended surfaces for targets near corners and the drawing of objects for targets near objects. This analysis also revealed no significant main effect of task order (interpretation task first: $M = .57$; evaluation task first: $M = .51$), $F(1, 90) = 1.00$, $p = .319$, $\eta_p^2 = .01$, no Task Order × Target Location interaction, $F(1, 90) = 0.31$, $p = .580$, $\eta_p^2 = .00$, no Task Order × Drawing Type interaction, $F(2, 90) = 2.26$, $p = .110$, $\eta_p^2 = .05$, and no three-way interaction, $F(2, 90) = 1.99$, $p = .143$, $\eta_p^2 = .04$. Thus, children who first used pictures to find locations in the room were no more likely than other children to judge that the pictures of surfaces were better at specifying corner locations and that the pictures of objects were better at specifying locations near objects. Using the pictures to find targets in the room did not enhance children's awareness of the useful information that the pictures presented.

Finally, a correlational analysis revealed that children who scored better on the interpretation task were not more likely to respond that surface drawings were more informative depictions of corner targets, and object drawings were more informative depictions of targets near objects, $r(94) = .090$, $p = .381$. There was no correlation between children's judgments that extended surface drawings were better depictions of corner targets and their actual performance at those targets, $r(94) = .032$, $p = .754$, and no correlation between children's judgments that object drawings were better depictions of targets near objects and their actual performance at those targets, $r(94) = .081$, $p = .434$.

Discussion

Children judged that object drawings were more informative of a target's location, regardless of whether the target was located at a corner near at an object. Children's evaluations contrast with their performance in the interpretation task of Experiment 1, which showed an interaction between picture type and target location, with no overall advantage for pictures of objects. In addition, there was no evident relation between children's judgments in the evaluation task of Experiment 2 and their performance in the interpretation task of Experiment 1. Children's higher evaluation of drawings of objects thus appears to operate independently of their actual use of the information in drawings, which varies depending on the locations of the targets that the drawings specify. These findings suggest that children's selective and adaptive use of surface or object information in pictures is not driven by explicit attentional mechanisms in which pictures allow children to identify what information is relevant in specifying certain target locations in the environment.

General Discussion

Children in the present study flexibly extracted different information from pictures depending on the location of the target that they were asked to find. Specifically, they showed a moderate tendency to use depictions of extended surfaces to find targets located in the corners of the room and depictions of objects to find targets located near objects in the room. Moreover, when presented with drawings depicting both surfaces and objects, children failed to integrate the two types of information to distinguish, for example, between a corner with a chair on its left versus on its right. Although previous studies have found that children more easily extract the content of symbols when those symbols represent scenes with highly visual fidelity and in familiar formats (Callaghan, 2000; Ganea et al., 2008; Liben & Yekel, 1996; Simcock & DeLoache, 2006, 2008), children in the present study performed no better with familiar-looking drawings of surfaces and objects together than with less familiar drawings that presented only the room's surfaces or only its objects.

These limitations echo those found in previous studies, which investigated children's ability to relate surface and object information using identical or similar pictures across different environments (Dillon & Spelke, 2015; Dillon et al., 2013). Dillon and Spelke (2015), for example, used similar perspectival pictures to indicate locations in an extended surface layout and on a manipulable object. They found that with the pictures of the layout, children located targets more successfully at corners, but with the pictures of the object, children located targets more successfully near landmarks. The same pattern of success, dependent on target location, was found in the present study, even though the present study varied the information in the pictures while keeping the referent of those pictures identical (Dillon & Spelke, 2015, varied the referent while keeping the pictures nearly constant). Thus, the limitations that children exhibit during early spatial-symbol reading are evident even when children are presented with the sorts of scenes and pictures of the scenes that they often encounter in their daily lives. Moreover, these results indicate that, unlike spatial language (Shusterman et al., 2011), spatial symbols may not encourage 4-year-old children to relate surface and object information during a search task.

The present study also brings to light a striking limitation to children's own knowledge and evaluation of their sensitivity to spatial information: Children chose drawings of objects as more informative about all target locations in the room. Such a failure may reflect a greater attention to objects than to surfaces in drawings or in the environment as much of toddler and preschool-aged children's perceptual development is defined by shifts in their attention from parts of objects to objects' global shapes (Smith, 2009; Smith & Jones, 2011; Yu, Smith, Shen, Pereira, & Smith, 2009). Moreover, most of preschool children's own drawings depict object information only: objects are often centered, floating randomly, or aligned on the page (see Winner, 2006 for a review). Additionally, although pictures with both surfaces and objects were by far the most prevalent among the Caldecott Winners, children may be sensitive to the significant differences in the percentages of object-only versus surface-only pictures in such books (see above and Supporting Information). Finally, it is possible that a simple preference for object drawings guided children's judgments of the usefulness of pictures in Experiment 2. We find this possibility unlikely, however, based on children's performance in the practice trial for that experiment. Children successfully judged that the practice picture with the blue and green dots versus purple and pink dots would "help us find these [blue and green] spots better" (the same language used in the test trials), despite some children having explicitly expressed a preference for the purple and pink dots. Thus, success in these practice questions also indicates that children likely did not interpret the test questions as probing their picture preferences.

Although the present study reveals limits to young children's use of information in pictures, it does not reveal whether older children and adults spontaneously navigate by pictures in a more integrated and explicit fashion, as they do during navigation without spatial symbols (e.g., Hermer & Spelke, 1994; Hermer-Vazquez et al., 2001). Moreover, it does not specify how young children allocate attention to pictures and how this attention might change through development. Using head-mounted cameras or eye-tracking devices, for example, may help to determine where children allocate attention during picture interpretation. Such a measure might also reveal differences between children who do and do not integrate surface and object information (as in, e.g., James, Jones, Smith, & Swain, 2014).

Finally, the present study does not indicate whether the ability to integrate spatial information during picture reading relates to more abstract spatial abilities such as those that support learning of

Euclidean geometry. Euclidean geometry focuses on abstract lines and points, and on their relations of distance and angle, which are common to physical surfaces and objects. Although preschool children attend primarily to distance but not angle when they navigate through extended surface layouts (e.g., Lee et al., 2012), and they attend primarily to relative length and angle but not distance when they recognize forms and objects (e.g., Izard & Spelke, 2009), adults and older children must integrate representations of distance and angle in order to solve even the simplest problems of Euclidean geometry (e.g., "What happens to the third angle of a triangle when the other two angles get bigger?"). Research suggests that such integration is achieved by about 12 years of age (Izard et al., 2011), but some aspects of Euclidean understanding remain tenuous, even for educated adults (Goldin, Pezzatti, Battro, & Sigman, 2011). Because the familiar task of recognizing depicted scenes elicits attention both to extended surfaces and to objects, interventions that increase children's awareness of their attention to different geometric information in spatial symbols might inform a pedagogy aimed at revealing the fundamental entities and relations of abstract geometry.

In addition to these applications, the present findings suggest that pictures of all kinds serve as media in which children deploy different symbolic spatial skills flexibly and automatically, without the need for explicit strategies modulating attention to certain spatial features over others. Such symbols represent both 3D scenes and objects, joining the spatial information guiding navigation with the spatial information used to recognize objects by their shapes. Although this information is not integrated in children's use of spatial symbols, cognitive scientists may elucidate the processes by which geometric abstractions, rooted in more complex geometric symbols like those underlying Euclidean constructions, arise by charting the development of children's engagement with the spatial relations presented in more common and easily understandable spatial symbols, including maps, perspectival art, and especially the ordinary drawings that are ubiquitous in children's lives.

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Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Appendix S1. Supporting Data