THE IMPACT OF OBJECT TYPE ON THE SPATIAL ANALOGIES IN KOREAN PRESCHOOL CHILDREN

A Dissertation

Presented to the Faculty of the Graduate School

Of Cornell University

In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

By

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May 2015

THE IMPACT OF OBJECT TYPE ON THE SPATIAL ANALOGIES IN KOREAN PRESCHOOL CHILDREN

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The present study investigated whether the perceptual simplicity of the objects depicting relations could facilitate young children's performance on a spatial analogies task. In Study 1, children of 3 to 5 years ($N = 120$) were asked to generalize spatial relations to instances comprised of a novel type of objects (cross-type generalization). Children were randomly assigned to generalize spatial relations either from a schematic sample image (i.e., geometric shapes) to three rich choice images (i.e., line drawings of realistic objects) or from a rich sample image to three schematic choice images. Children across age performed better with the schematic samples than with rich samples. Study 2 examined generalization of spatial relations to instances comprised of similar types of objects, in children of the same age range ($N = 121$). In this within-type generalization test, only 5-year-old children, but not 3- or 4-year-old children, benefited from the schematic samples. The results overall indicate that perceptually simple objects are more effective in facilitating young children's generalization of spatial relations than perceptually rich objects. Additionally, across both studies, young children's spatial vocabulary, especially their acquisition of locative terms, was positively associated with their spatial analogy skills, suggesting an intimate link between particular spatial words and spatial analogies.

Keywords: spatial analogies, generalization, object features, relational learning, spatial vocabulary

BIOGRAPHICAL SKETCH

Youjeong Park received her Bachelor of Arts degree from Seoul National University in South Korea in 2002, and her Master of Arts in Child and Family Studies degree, also from Seoul National University, in 2006.

To my mom, Ki-hong Lee, who loves, supports, and encourages me all the time from heaven,

my dad, Jae-keun Park, whose trust in me always encourages me to believe in myself,

and my grandmother, Jeong-nyeoh Kim, who is one of my best friends and best supporters

ACKNOWLEDGMENTS

I would like to gratefully and sincerely thank Dr. Marianella Casasola for her guidance, understanding, patience, and support during my graduate studies at Cornell. She encouraged me to grow as an independent thinker, a research scientist and a writer. For everything you have done, I thank you, Professor Casasola. You've been a tremendous mentor for me. I would also like to thank my committee members, Professor Barbara Lust and Professor Tamar Kushnir, for serving as my committee members, for letting my defense be an enjoyable moment, and for their brilliant comments and suggestions. I have benefited greatly from the discussions with them since my first year. I am so lucky to carry all the valuable experiences and models to my country, Korea.

I would also like to thank undergraduate research students of Cornell Infant Studies Lab, especially Lauren O'Neil and Wendy Wei, for their help with constructing the stimuli, and my cousin, Youngjoo, for drawings the pictures for my dissertation study. A special thanks to the directors and teachers of the preschools in Seoul for allowing me to recruit and test children, and of course the parents and children who kindly agreed to participate. I am also grateful for the freidnship of Nadia Chernyak, Qingfang Song, Yang Yang, and Yue Yu, who have been there to support me when I was away from my family.

Finally, and most importantly, I would like to thank my husband Jinwook. His support, encouragement, patience, and unwavering love was what sustained me thus far. Words cannot express how grateful I am to my mother-in-law, my mother and father for all of the sacrifices that they've made on my behalf. At the end I would like to express appreciation to my daugher Hyejeong for being such a happy and healthy child and being so supportive for her studying mom.

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CHAPTER 1

INTRODUCTION

Sensitivity to the spatial arrangement between and among objects is evident early in development. Neonates manifest the ability to extract the invariant relative positions of two objects in the horizontal and vertical planes against varying absolute locations (Antell & Caron, 1985; Gava, Valenza, & Turati, 2009). Infants continue to develop their ability to form categorical representations of the spatial relations (e.g., Behl-Chadha & Eimas, 1995). At first, infants' categorical representations of spatial relations are tied to particular objects that they have experienced. Later, by 6 months, they can form *abstract* categorical representations of spatial relations independent of specific objects (Casasola, Cohen, & Chiarello, 2003; Quinn, Cummins, Kase, Martin, & Weissman, 1996; Quinn, Polly, Dobson, & Narter, 1998). That is, infants can generalize some spatial relations to previously unseen objects in the same spatial relation. Thus, a basis for generalizing spatial relations is established in infancy (for a review, see Casasola, 2008).

Yet, despite its early inception, young children do not always generalize the spatial arrangement from one set of objects to another. For example, in a mapping task where similarity in relative position (left, middle, and right) and relative size (the smallest, medium, the largest) was pitted against similarity in objects' superficial features, only approximately half of the 3- and 4-year-old children (an average of 47% across both ages) made relational responses (Rattermann, Gentner & DeLoache, 1989, 1990). In another similar mapping task, children were presented with two identical three-tiered boxes that differed only in color, with each box containing three cards. The experimenter showed the child the location of the "winner" card in the Hiding box and asked the child to point at the winner card in the Finding box. The cards of the Hiding box were all blank and gray, and all cards in the Finding box were blank and blue. Thus, all cards in the Finding box were equally similar to the winner card in the Hiding box. The winner was always in the same spatial location in each set of boxes (i.e., top, middle, or bottom). Even though relative position was the only basis for drawing correspondences in this mapping task, about 45% of 3-year-old and 64% of 4-year-old children chose location matches. Even at older ages, young children still demonstrate difficulties mapping relative positions in a spatial mapping task when children can choose options that match on the objects rather than location (Loewenstein & Gentner, 2005).

Also, studies examining children's understanding of the model-room correspondence indicate that young children's appreciation of the correspondence is strongly influenced by object similarity (e.g., comparison between DeLoache, 1987 and DeLoache, Kolstad, & Anderson, 1991; Blades & Cooke, 1994). Three-year-old children draw on their knowledge of location in the model to find a toy hidden in the same place in a real room when the corresponding items of furniture are highly perceptually similar, but fail to do so when the color and pattern of the items mismatch between the model and the room (e.g., rust-colored chair and blue-color chair) after watching a toy being hidden in one model room. Together, these findings suggest that the ability to generalize spatial arrangement continues to develop during preschool years.

The present study was aimed at further investigating young children's ability to generalize spatial arrangements, using a task of spatial analogies in which children are asked to generalize the spatial arrangement in one target image to one of three choices.

We asked four specific research questions: (1) whether children generalize some spatial relations (particularly, containment relations) more readily than others (support relations); (2) whether children's generalization of spatial relations is better promoted by perceptually simplified objects rather than more perceptually rich objects; (3) whether children's generalization of spatial relations undergoes considerable development between the ages of 3 and 5 years; and (4) whether children's generalization of spatial relations is more strongly associated with a certain type of spatial vocabulary than another. Below we present background for each research question.

Spatial Relation Type and Generalization

Work on infant spatial categorization suggests that infants attend to and generalize some spatial relations more readily than others, thus abstract categorical representations of spatial relations emerge at different points in development for different spatial relations (Casasola & Cohen, 2002; Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003; Quinn et al., 1996). For example, Casasola and colleagues found that infants' ability to form the category of containment relations (i.e., one object placed IN another) is evident at an earlier age (around 6 months) than the category of support relations (i.e., an object placed ON top another) or that of tight-fit relations (Casasola & Cohen, 2002; Casasola et al., 2003). Quinn and colleagues also demonstrated that infants form abstract categorical representations of *above-below* relations earlier than that of *between* relations.

Language acquisition studies also show differences in ease with which children acquire different spatial prepositions. For instance, the preposition *in* expressing containment relations is understood before (and produced more than) the prepositions, *on* and *under* (Bowerman, 1996; Brown, 1973; Clark, 1973; Furrow, Murray, & Furrow, 1986; Halpern et al., 1983; Johnston & Slobin, 1979) while *on, in,* and *under* are among the early acquired spatial terms in English-learning children (e.g., Bremner & Idowu, 1987; Clark, 1973; Johnston & Slobin, 1979; Meints, Plunkett, Harris, & Dimmock, 2002; Tomasello, 1987). Further, prepositions requiring one referent (e.g., *on*, *in, under*) are acquired earlier than those requiring two referents (e.g., *between*, *middle*) (Internicola & Weist, 2003; Johnston & Slobin, 1979). Moreover, nonverbal behaviors such as construction of spatial relations also show preference for *in* over *on* and *under* during toddlerhood (Corrigan et al., 1981; Sinha, 1998). Thus, these findings together suggest the possibility that spatial relations may vary in saliency or the degree to which they are included in infants' and toddlers' representations of stimuli.

There is evidence raising the question whether these discrepancies continue to exist in preschool children's *use* of relations. When presented with a large landmark and two identical small landmarks, one *in* the large landmark and the other *next to* the large landmark, 3- and 4-year-old children are more likely to successfully disambiguate the location of a targeted small landmark in their description when it was *in* the large landmark than when it was *next to* the large landmark (Plumert & Hawkins, 2001). In addition, when asked to find a target object following directions, 3-year-old children are faster to initiate their searches when they are told that the small landmark is *in* the large landmark than when they are told that it is *next t*o the large landmark. Hence, in both marking and coding of spatial relations preschool children show a bias for some spatial relations (also see Plumert, Ewert, & Spear, 1995 for similar finding regarding support relations). Thus, possibly preschoolers *generalize* some spatial relations more easily than others, parallel to the discrepancies observed from younger children.

Although many studies on children's relational transfer tested multiple relations, there has been little research focusing on comparing preschool children's generalization across different types of relations. In the present research, we varied the spatial relation in the target image to assess how the relation type may influence children's spatial analogies performance. Specifically, we tested whether containment relations, which young infants categorize in their first months with diverse, rich objects, would be generalized at more ease than other relations, especially support, which are not as easily categorized by infants. In addition to containment and support, we tested *above* relations to explore potential differences from support and containment relations. Prior work has revealed that young infants are able to categorize *above* (or *over*) relations in their first months (Quinn et al., 1996), similar to containment relations. However, their generalization of *above* relations has been tested only with a fixed referent (i.e., a bar) and geometric shapes, not with images of actual objects. Thus, it was an open question whether *above* relations would be generalized with the same ease as containment relations, and with more ease than support relations.

Object Type and Generalization

In addition, we systematically varied the type of objects depicting the spatial relations to assess how this variable may impact children's performance on a spatial analogies test. A few earlier studies examining children's spatial analogies found that preschool children successfully generalized relative positions of a familiar object (e.g., body parts such as head, knee, and feet) to another object in a different domain (e.g., mountain, tree) (Gentner, 1977). However, several recent studies testing transfer of relations demonstrated that children and adults' relational transfer is facilitated when the relations are depicted with perceptually simplified or abstract objects (e.g., Kaminski, Sloutsky, & Heckler, 2008; Kaminski & Sloutsky, 2010; Rattermann, Gentner, & DeLoache, 1989, 1990; Son, Smith, & Goldstone, 2011; Uttal, Amaya, Maita, Hand, Cohen, O'Doherty, & DeLoache, 2013; but see Petersen & McNeil, 2013 for more nuanced findings). For example, Rattermann, Gentner, and DeLoache (1989, 1990) found that in a mapping task where object match and relative size or position match conflicted, young children made more relational choices (focusing on relative size or position) when the objects were perceptually simple and identical to each other (three clay pots that differed from each other only in size) than when they were perceptually rich and diverse from each other (a toy house, a toy car, and a decorative mug, each also varying in size). Similarly, young children transferred an ABA or BAA relation better when it was depicted with shapes such as three triangles than with perceptually rich objects such as three dogs (Kaminski & Sloutsky, 2010; Son, Smith, & Goldstone, 2011). Also, the use of abstract geometric shapes was more effective than the use of perceptually rich and concrete objects in promoting transfer of mathematical concepts for both children and adults (Kaminski, Sloutsky, & Heckler, 2006, 2008; Kaminski & Sloutsky, 2009).

This advantage of perceptually simple objects over rich ones in relational transfer has been attributed to several mechanisms, including (1) shortcutting the abstraction process by providing a *ready-made* abstract representation of a relation, with irrelevant features already omitted (the abstraction view, e.g., Son, Smith, & Goldstone, 2008), (2) reducing the probability of attending to the objects themselves rather than the relation among the objects by reducing the amount of object information to process and allowing more cognitive resources allotted to processing relational information (the perceptual distraction or information processing view, e.g., DeLoache, 1987; Goldstone & Sakamoto, 2003; Kaminski & Sloutsky, 2009; Kaminski, Sloutsky, & Heckler, 2008; Rattermann, Gentner, & DeLoache, 1990; Uttal, Scudder, & DeLoache, 1997), and (3) having high symbolic nature in that simple objects are more likely to be considered to refer to something else than richer objects (symbolic reasoning view, Kaminski, Sloutsky, & Heckler, 2008, 2010; Uttal, Scudder, & DeLoache, 1997; Uttal et al., 2013). In other words, the references of the simple geometric shapes are widely open, whereas the references of rich objects are highly limited to specific objects presented. Finally, another view concerns how rich objects may hamper relational transfer: (4) the learner's established knowledge of the meaning or functions of rich objects makes it difficult for them to see the rich objects as the components of a relational set (Petersen & McNeil, 2013).

Albeit using different terms to explain the mechanism, these studies together cast doubt upon the common, long-held view among teachers and parents that children can better learn complex relational concepts with perceptually rich, concrete, and interesting objects or examples. In addition, the findings can have important practical implications for constructing and using educational materials to improve children's generalization of relational concepts.

However, the issue has been rarely applied to the domain of spatial relations, with only a few studies directly testing the effect of object simplicity on spatial learning or transfer of spatial relations. Among them, studies by Rattermann and colleagues (1989, 1990) showed an advantage of perceptually simpler objects, but generalization of relative position in their studies was confounded with generalization of relative size of objects.

Other than these studies, to our knowledge, there is only one recent study that directly examined the impact of perceptual complexity of the objects depicting spatial relations on infants' generalization of support relations (Park & Casasola, in revision). Interestingly, the study yielded results inconsistent with previous findings, with infants of 8 and 14 months forming an abstract categorical representation of a support relation when habituated with more perceptually complex objects (i.e., blocks with many decorative features) but not perceptually simpler objects (i.e., blocks with no decoration).

Although the discrepant finding from infant work might raise the question of whether spatial relations differ from other relations such as monotonicity and symmetry with respect to the role of object perceptual features in generalization (e.g., spatial relations are perhaps more concrete than other relational domains in that they are perceptually accessible), spatial relations nevertheless share important characteristics with other types of relational information. For example, in order to generalize a spatial relation, (1) one must look beyond the objects (the components) to note the spatial relation, and (2) one must be able to recognize the relational commonality among instances. Therefore, one reasonable possibility is that the differences in findings between the infant study and other previous studies are attributed to methodological differences, rather than to the differences in the domain of relations.

Among a number of methodological differences, three might have mainly contributed to this discrepancy between the findings from the infant spatial categorization study and those reported by most previous studies. First, the discrepant findings may be related to developmental differences. Note that most previous studies demonstrating the advantage of simple objects tested older children or adults. One possibility is that although both infants and older learners exhibit difficulty responding to relational information, the source of their difficulty may differ, and so may the type of cue that best aids them to attend to the relation. More specifically, for older children and adults, who likely have rich knowledge about objects, features (e.g., wings, antennas), and relations, the difficulty may stem from many possible concepts that an instance can convey. For these learners, a hint telling which aspect of information (i.e., relation) they should focus on among the many may be effective. Thus, depictions using perceptually simplified objects that selectively present the intended relation only may provide such hint (negative hint that omits other possibilities). However, for young infants, who likely have only sparse knowledge about objects, features and relations, the difficulty may arise because they hardly include relational information in representation. Thus, for these learners, an additional cue making the intended relation more salient (and more interesting) may be more effective (positive hint that adds saliency of a relation). For example, the infant spatial categorization study compared monochromatic blocks and blocks containing moderate decorative features. Moderately decorated objects resulted in more contrasted outcomes (i.e., *visual changes*) than the minimalist objects when the spatial relations of support and containment were compared. More specifically, when a monochromatic block was placed in its referent box, the only perceptual change was in the degree to which the object remained visible. In contrast, when a richly decorated block was inserted into its referent box, several of its features became occluded. Thus, richer objects may have offered an advantage by providing more perceptual changes, changes that may have cued infants to the change in spatial relation. Therefore, the presence of rich features may have made the spatial relation information more likely to be noted by young infants, facilitating their formation of the spatial category. While these additional perceptual cues may be effective for younger children's recognition of a relation and consequently help generalization, the beneficial effect of object perceptual simplicity on relational generalization may increase with children's development (or acquisition of rich knowledge).

Another methodological difference that may be potentially important lies in the structure of the generalization task, namely, the presence of comparison examples (and sufficient time to compare them). The infant study presented each infant with four exemplars to compare (or habituate to) before the generalization test, whereas most other previous studies asked children to generalize from a single set of objects. Possibly, the advantage of a simple instance as a *ready-made* abstract representation works best when the learner must grasp the relational structure from a single instance, but is less pronounced when the learner is given multiple exemplars of the relation. There is indirect suggestive evidence for this possibility. In one study, the advantage of perceptually simple instantiation of ABA and BAA relations was found when one instantiation was fixedly used as the basis of transfer, but not when the instantiation used as the basis of transfer varied on every trial (Son, Smith, & Goldstone, 2011). Although the study did not manipulate the number of exemplars serving as the basis of generalization, their findings suggest, as noted by the researchers of the study, that the advantage of perceptually simple instantiation may be most prominent when it functions as a *model* of richer instances of the relation. In the infant spatial categorization study, the instances did not need to serve as a model for the support relation. Instead, viewing multiple instantiations of a spatial relation may have resulted in an abstract representation anyway.

Possibly for this reason, the benefit of object simplicity was not apparent in the infant study.

Lastly, the different findings may be attributable to the fact that the rich objects in the infant study did not have established meaning or usage as objects. While the rich objects used in most other previous studies were familiar animals and everyday objects (e.g., dogs, cupcakes, and cups containing water), the decorated boxes in the infant study were likely to be novel to the infant (e.g., a box with two wings and checkerboard pattern body). Recall that a proposed mechanism of how rich objects might hinder relational learning is that the established functions of rich, concrete objects interfere with the learner's ability to use them for different usage (seeing them as a component of a relation) (Petersen & McNeil, 2013). Thus, infants' successful categorization with rich objects may have been partly due to the novelty of the rich objects. Taken together, these considerations raise the hypothesis: If (1) the learners are knowledgeable (e.g., older subjects), (2) the rich objects are familiar to the learners, and (3) there is limited opportunity to compare multiple exemplars before generalization, then the advantage of simplicity should be observed in transfer of spatial relations.

In sum, research to date has provided no clear evidence that schematic depictions using perceptually simplified objects such as geometric shapes promote generalization in the spatial domain. Although a discrepant finding emerged from an application of the question to the infant spatial categorization experiment, several procedural and material differences between the infant categorization experiment and other studies leave open the possibility that perceptually simple objects aid transfer of spatial relations if the generalization setting is similar to other studies. Therefore, we tested preschoolers using a single-exemplar-based generalization task and pictures of familiar rich objects versus geometric shapes in the present study. We predicted that preschool children in the present study would show better generalization of spatial relations with schematic than rich objects, comparable to previous findings with other relations.

Development of Generalization of Spatial Relations

Most researchers agree that the ability to detect relational commonalities increases with development. For example, the ability to generalize symmetry and monotonic relations increases during the preschool years (Kaminski & Sloutsky, 2010; Kotovsky & Gentner, 1996; Rattermann, Gentner, & DeLoache, 1989, 1990). Also, school-aged children are more adept at transferring a structure of a story to a new set of characters than preschool children (Gentner & Toupin, 1986). Further, in interpreting analogies or metaphors, older children and adults are more likely to attend to common relational roles than younger children who are likely to focus on objects' superficial commonalities (Gentner, 1988).

Several factors have been proposed to underlie this developmental increase in relational response (or so-called 'relational shift'). They include (1) increase in domain knowledge (e.g., Gentner, 1988; Gentner & Rattermann, 1991), (2) increase in processing capacity such as working memory (Halford, 1993), and (3) increase in inhibitory control (Richland, Morrison, & Holyoak, 2006). Although the domain-knowledge accounts explain how young children successfully generalize some relations (e.g., body-parts) but not others (e.g., comparison between the findings from the two studies, Gentner, 1977, 1988), they do not explain well why young children solving relational mapping tasks sometimes still choose their answers based on object properties and overall appearance in spite of understanding the relations (e.g., bigger than) (Rattermann, Gentner, & DeLoache, 1989, 1990). These findings may be better accounted for by the inhibitory control account (e.g., Thibaut, French, & Vezneva, 2010). Moreover, the processing capacity theory explains how one becomes able to use increasingly complex relationships (Halford, 1993) such as solving analogy problems consisting of multiple relations. Thus, the observed developmental increase in relational response may be an outcome of multiple factors.

In the domain of space, there is evidence suggesting that young children's ability to detect and use common spatial relations significantly increases during the preschool years. More specifically, children's accurate mapping of *top-middle-bottom* positions between two boxes increased from 45% to 64% over the short age range of 3;8 to 4;1 when no linguistic cue (i.e., spatial label) was provided (Loewenstein & Gentner, 2005). Also, in a mapping task where relative position match and appearance match were both present, children's correct mapping of *left-middle-right* positions (albeit confounded with relative size) increased from 54% to 95% with perceptually sparse stimuli, and from 32% to 68% with perceptually rich stimuli, between the ages of 3 and 5 years (Gentner & Rattermann, 1991; Rattermann & Gentner, 1998).

As can be noticed from these findings, however, available data are limited to children's ability to match relative positions of three objects on vertical or horizontal planes, resulting in a lack of developmental data on how readily children use the basic spatial relations between two objects such as *on*, *in*, and *above* during the preschool years. In the present study, we attempt to track developmental changes in the ability to generalize these spatial relations from one instance to another between the ages of 3 and

5 years. Since infants have been shown to be able to form abstract categorical representations of these spatial relations from exposure to a set of exemplars (see Casasola, 2008 for a review), our data would provide insight into how generalization of spatial relations develops over an extended time span.

Linkage Between Spatial Language and Spatial Analogies

Spatial language ability and spatial reasoning skills are often linked to each other, with one predicting the other. For instance, infants' production of prepositions (measured by 26 prepositions of MCDI) predicts their performance on a place-learning task (Balcomb, Newcombe, & Ferrara, 2011). Specifically, in this spatial task, infants were placed in a round enclosure and saw a puzzle hidden under the floor at one location. They were then disoriented and asked to find the puzzle. Infants' ability to locate the goal object in a maze correlated with their production of prepositions, but not with their overall language production including nouns and verbs, suggesting a spatial-specific linkage between language and cognition.

Within this spatial-specific link, however, it remains unclear *how specifically* the spatial reasoning skills and spatial language are related. Some findings support a more general link between spatial language and spatial skills. For instance, in a longitudinal study, children's production of broad spatial terms describing object shapes (e.g., circle), spatial features (e.g., curvy, side), and dimensions (e.g., big, long) as toddlers predicted their performance on multiple spatial tasks such as a task of spatial transformations and spatial analogies as preschool children (Pruden, Levine, & Huttenlocher, 2011). Possibly, spatial input, such as parental spatial talk, influences the amount of spatial language that children produce, which in turn, promotes children's attention to spatial aspects of the world around them in general and ultimately spatial thinking (Pruden, Levine, & Huttenlocher, 2011).

Despite the evidence for a broader link between spatial language and spatial thinking, several studies indicated more specific links between spatial reasoning skills and acquisition of spatial language. For example, on a midpoint search task where children had to find an object hidden in the middle of two landmarks, young children's performance positively correlated with their acquisition of the spatial terms, *middle* or *between* (Simms & Gentner, 2008). In addition, 5-year-old children's performance on a landmark-based reorientation task, where the left-right relations relative to a landmark wall were useful to find a hidden object, was associated with their ability to produce phrases expressing left-right relations, but not with the spatial terms *above/below* nor with *in front of/behind* (Hermer-Vazquez, Moffet, & Munkholm, 2001). Along similar lines, adult Nicaraguan signers' performance on a disorientation search task was related to consistent marking of left-right relations in a language elicitation task, but not to their marking of the ground objects in their spatial descriptions (Pyers, Shusterman, Senghas, Spelke, & Emmorey, 2010). Marking of the ground objects, instead, was associated with performance on a rotated box task in their study. These findings together suggest that the link between spatial language and spatial cognition may be considerably *aspect-specific*.

Taken together, one reasonable possibility is that although there may be some positive relationship between broad spatial language and children's spatial reasoning skills in general, some aspects of spatial language are more strongly associated with a particular spatial reasoning skill than others. That is, aspects of spatial language that are directly relevant to solving a given spatial task may be more intimately associated with the given spatial reasoning skill than other aspects of spatial language. To test this possibility, we tested children's shape vocabulary and locative vocabulary, and examined the relationship between children's generalization of spatial relations (performance on a spatial analogies test) and each aspect of spatial language.

The two aspects were thought to be ideal for testing the hypothesis for the following reasons. Shape vocabulary, the names of basic geometric shapes such as circle, triangle, and rectangle, are often taught to preschool-aged children (Newcombe & Frick, 2010). Also, during the preschool years, children learn basic shape names and develop their concepts about shapes (Clements et al., 1999; Fuson & Murray, 1978; Hannibal & Clements, 2008). Identifying geometric shapes requires one to attend to spatial properties such as curvilinear or rectilinear, parallel, corner, side, open or closed. However, it is arguably not directly relevant to solving a spatial analogies test. In contrast, locative terms, terms denoting a spatial relation between or among objects such as front, back, left, and right, may be more directly relevant to solving the spatial analogies test. Also, children acquire considerable number of locative terms during the preschool years (Bowerman, 1996; Bremner & Idowu, 1987; Brown, 1973; Clark, 1973; Corrigan et al., 1981; Furrow, Murray, & Furrow, 1986; Halpern et al., 1983; Internicola & Weist, 2003; Johnston & Slobin, 1979; Meints, Plunkett, Harris, & Dimmock, 2002; Tomasello, 1987; van Geert, 1986). Therefore, we predicted that young children's shape vocabulary would have a less intimate link with the ability to generalize spatial relations (performance on a spatial analogies test) than their vocabulary for locative terms.

Spatial Analogies Test

To test young children's generalization of spatial relations, we used a test of spatial analogies. Spatial analogies tests have been used with preschoolers with variations (Gentner, 1977; Pruden, Levine, & Huttenlocher, 2011). An analogy test is thought to involve several sub-processes: (1) The learner represents a target domain or instance; (2) Prior domain or instance is retrieved; (3) Elements of two domains or instances are aligned and structure is mapped across domains or instances. Particularly, we modified the Spatial Analogies test, a subtest of the Primary Test of Cognitive Skills (Huttenlocher & Levine, 1990) in which children are asked to select which of four options went best with a target image. The original spatial arrangements in Huttenlocher and Levine's (1990) test were combinations of various spatial aspects such as object shape, size, orientation and amount of overlap and so on. Consequently, those spatial arrangements did not correspond to a single English spatial word. For the purpose of the present research, we replaced the original spatial relations with the spatial relations of our interest (i.e., *on, in,* and *above*), each of which corresponded to a single English spatial word. Also, we modified the original test so that children were presented with three choices rather than four to reduce children's load in comparing the choices. Finally, the original images utilized both geometric shapes and line drawings of concrete objects, with object type not systematically varied. We systematically varied the type of depictions for our purpose (see Appendix A).

The spatial analogies test was thought to be ideal compared to other tests of generalization such as the label extension task (e.g., Son et al., 2008) and the winner/sticker-finding game (e.g., Loewenstein & Gentner, 2005; Rattermann, Gentner, & DeLoache, 1990) for the current purpose, given that children likely know the linguistic labels for the spatial relations examined and that it allows us to test the ability to match a spatial relation itself in a target image, rather than the ability to match a component object playing the same relational role in a set.

Cross-type versus Within-type Generalization

In the present research, two types of relational transfer were examined to better understand the potential effect of object type on relational transfer. First, we examined cross-type generalization in which the spatial relations were transferred between highly dissimilar types of objects, either from schematic objects to rich objects or from rich objects to schematic objects. It was this type of transfer that several previous studies (but not the infant spatial categorization study) utilized and showed the advantage of simple objects. For example, most studies by Kaminski and his colleagues (2008, 2009, 2010) compared between Geometric shapes to Rich objects and Rich objects to Rich objects. By beginning with the cross-type spatial analogies test, we first tested the hypothesis that simplified objects would be more advantageous than rich objects in generalization of spatial relations if the transfer settings were similar to the previous studies testing older learners. In addition, it is known that surface similarity largely affects children's detection of a relational correspondence (e.g., DeLoache et al., 1991; Gentner & Toupin, 1986). By testing cross-type generalization, we aimed to control for the similarity distance between the sample (the target image) and the options and examine which type of objects better promotes children's generalization of a spatial relation. Next, in the second study, we examined within-type generalization where the transfer of spatial relations occurs between the same types of objects, either from schematic objects to schematic objects or from rich objects to rich objects. Again, with the similarity distance between the sample and the choices controlled for, we could compare the effectiveness of each type of samples (i.e., simpler or richer) in promoting near transfer. It was this type of transfer that the infant spatial categorization study used. Thus, it would allow us to explore whether the condition of generalization also influenced the effectiveness of the sample type. In addition, investigating the within-type generalization would rule out an alternative explanation of the possible results of the first study (see discussion of Study 1).

Summary

In sum, drawing upon work on relational learning and infant spatial categorization, the present research investigates young children's generalization of spatial relations, *above*, *on*, and *in,* with perceptually more schematic versus richer objects at age 3, 4 and 5 years, using a test of spatial analogies. Our main purpose was to investigate the impact of object type on young children's generalization of spatial relations, comparing the affordance of two types of visual representations of relations (schematic versus rich) in terms of generalization of spatial relations. We also aimed to test generalization of spatial relations in the absence of salient object match, unlike when all choices were object matches (e.g., Loewenstein & Gentner, 2005) or when a single choice was salient object match (e.g., Rattermann, Gentner, & DeLoache, 1990). We also had several secondary goals in this research. We aimed to document possible effects of spatial relation and the child's age, tracing development of generalization of the three spatial relations during the preschool years. Particularly, we aimed to test whether the gap between containment and support relations observed in infant spatial categorization would extend to early childhood. Lastly, we aimed to provide the first test of a more intimate link between spatial analogies and locative terms acquisition.

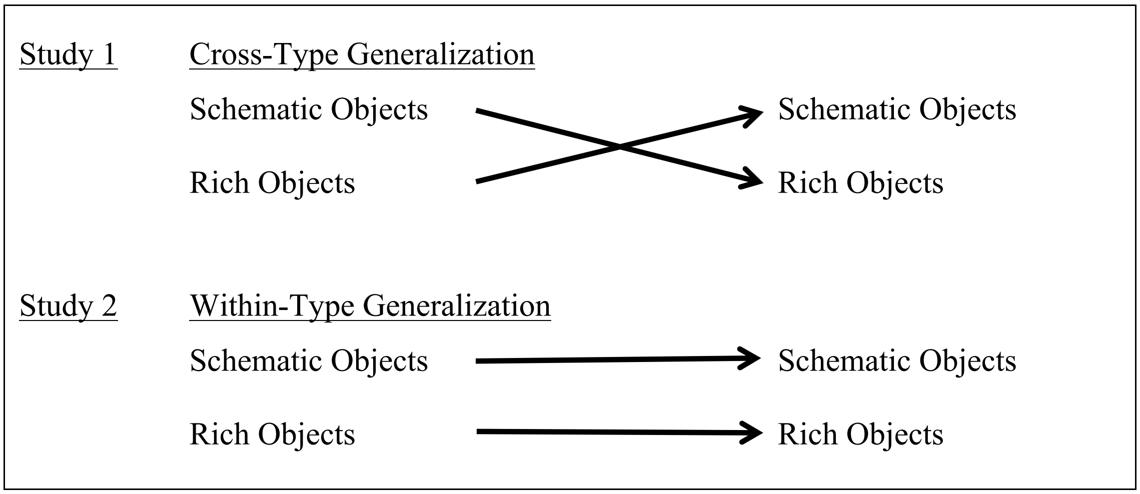


Figure 1. A schematic depiction of Study 1 and Study 2.

CHAPTER 2

STUDY 1

The goal of the first study was to examine the possible effects of spatial relation, object type, and child age on young children's cross-type transfer of spatial relations. If generalization of spatial relations shares important characteristics with transfer of other relational information, preschool chidren would show better generalization of spatial relations with simplified objects than rich ones, in a single-exemplar-based generalization task that contrasts familiar, rich objects to simple objects. Also, if the discrepancies among spatial relations in early spatial categorization continue to exist in preschool children, then preschool children should generalize containment relations with greater ease than other relations, especially support. In addition, while children's generalization of spatial relations increases with age, it will be closely associated with their spatial vocabulary, particularly their acquisition of locative terms.

Method

Participants

Participants were 120 children in three age groups: 40 3-year-old, 40 4-year-old, and 40 5-year-old children. There were equal numbers of male and female children for each age group. No child was excluded in this study. The range, mean, and standard deviation of age are presented in Table 1. Children were recruited from eight daycare centers in Seoul, Korea. Parental consent forms and a letter about the study were distributed by the daycares in advance of the testing date, and children who returned completed consent forms took part in the study. Children's socioeconomic backgrounds varied but the majority of participants were middle class. All children were from homes in which Korean was the primary language spoken.

Materials

Spatial analogies test. Two corresponding sets of spatial analogy items were constructed for this study: one Rich-to-Schematic set and one Schematic-to-Rich set. The Rich-to-Schematic set consisted of 12 spatial analogy items, 4 items of each target spatial relation (*on*, *in*, and *above*). Each spatial analogy item consisted of 4 pictures, one sample and three choices. In each picture, two objects, one smaller (i.e., figure object) and one larger (i.e., referent object), depicted a spatial relation (e.g., a dog *in* a doghouse) without background scene. Always, only one of the three choices matched the sample with respect to the spatial relation depicted (spatial relational match). Spatial relations for the non-matches were randomly chosen from the relations of *above*, *below*, *on*, *in*, *left to*, and *right to*.

A list of 48 distinct rich scenes and another list of 48 distinct schematic scenes were created. The rich scenes were selected with the following considerations: (1) The constituent objects should be fairly familiar to young children (e.g., a spoon, a bowl); and (2) Depicted spatial relations must be ones that could occur between the constituent objects in the real world (e.g., a spoon *in* a bowl). These criteria ensured that children could individuate two objects in spatial relations involving contact, such as *in* and *on,* and could easily understand the spatial relations between the objects from static images. Then black and white line drawings of the 48 scenes were created either by transforming photographs or clip arts collected from either a Google image search or an OpenClipArt into simpler line drawings or by asking an illustrator to draw. Examples of the final pictures are presented in Figure 2.

The schematic scenes were constructed by replacing the objects of the rich scenes with geometric shapes (see Figure 2). Specifically, sixteen commonly used basic geometric shapes were selected based on children's shape books. The black and white line drawings of the shapes were created on Microsoft PowerPoint 2011 slides. The size and the width-length ratio of the geometric shapes were diversified in order to create 48 distinct pictures.

Once the pictures were ready, 12 spatial analogy items for each set (Schematic-to-Rich condition and Rich-to-Schematic condition) were created using Microsoft PowerPoint slides. In each item, a sample picture was shown at the top center of the slide, and then three options were shown below the sample side by side. The size of each picture was 6.5 cm x 6.0 cm when displayed on the monitor. The location of correct choice was counterbalanced across trials.

An additional sample of 20 three- to five-year-old children was tested on each object version of the task to ensure that the tasks were suitable for the targeted age groups. Children were highly engaged in both object sets of the spatial analogy task. Completion times ranged from approximately 5 to 8 minutes. For a few items, the objects in the target were too similar to an object in one of the three choice options and children tended to choose the test option with a similar shape as the target. To avoid children choosing a response that matched the target because of a salient match in object appearance, the objects in these test options were replaced with highly dissimilar objects.

Once all the spatial analogy items were ready, three different presentation orders were created, using an online research randomizer (www.randomizer.org). The items were presented in 4 blocks, with 3 different target relations per block. Within each block, the order of target relations was randomized. Once the three presentation orders were ready for the Rich-to-Schematic set, corresponding spatial analogy items were arranged in the same order for the Schematic-to-Rich set so that the two sets were matched in their presentation order.

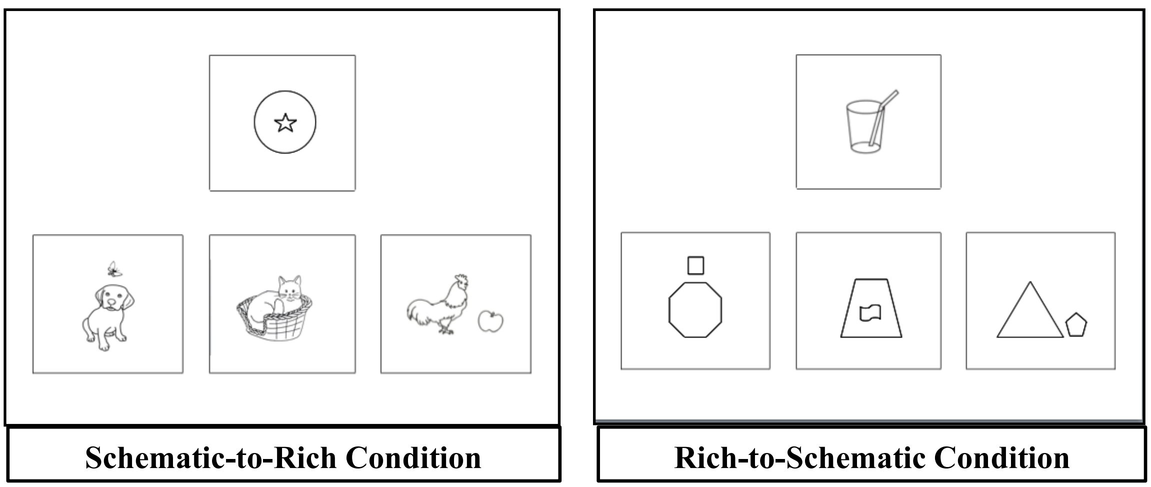


Figure 2. A sample spatial analogy item in each condition of Study 1. See Appendix A for a full list of spatial analogy items used in the present research.

Spatial language test. To assess children's acquisition of shape names and locative terms, a spatial language test developed by Casasola (2013, Wei & Casasola, 2014) was used. This test measures children's comprehension and production of shape names and locative terms. The first section measures children's productive shape vocabulary. It consists of 13 geometric shapes (color pictures on a white background). Children are asked to name each shape. The second section of this test measures children's comprehension of shape names. It consists of 5 questions, in each of which four geometric shapes (color pictures on a white background) are simultaneously shown and children are asked to point to the shape that the experimenter asks for (i.e., diamond, semi-circle, hexagon, and pentagon). The third section measures children's production of locative terms. It includes 8 pictures of a toy bear in diverse locations in relation to a cup. Children are asked to verbally describe where the bear is in relation to the cup. Finally, the section measuring children's comprehension of locative terms consists of 8 questions. Pictures of a bear in diverse relative locations to a cup are presented. In each question, 2 to 4 pictures of bear-and-cup or bear-and-board that are used in the third section (i.e., production of locative terms) are again presented, and children are asked to point to the picture that matches the closest to what the experimenter asks for (e.g., In which picture the bear is *below* the cup?) (see Appendices C and E).

Procedure

Children were randomly assigned to one of two conditions and one of three fixed presentation orders for each condition (e.g., Schematic-to-Rich, Order 1). They were individually tested in a quiet room in their childcare center. Children sat next to the experimenter at a table, and completed the two tests: a spatial analogies test and then a spatial language test. All tests were presented as slides, on a laptop computer screen. Prior to beginning, the experimenter explained the spatial analogies test to the child. Specifically, children heard the following instructions. "Now we are going to play a game of finding matches of picture cards. First, I will show (the child's name) one picture. Then I will show three more pictures. Then, (the child's name) will look at the pictures carefully, and tell me which one of three pictures is the best match to the first shown picture. OK? Are you ready?" The exact instructions in Korean are presented in Appendix B.

As in previous studies (e.g., Huttenlocher & Levine, 1990), the experimenter then administered a practice trial before the actual trials. Specifically, in both conditions, the experimenter introduced the child to a practice trial, saying "We will do a practice one first so you can see how the game works." For this practice item, the experimenter presented the child with a printed spatial analogy item on a letter-size piece of paper, which was selected from the Huttenlocher and Levine (1990)'s analogies subtest of Spatial Battery. Children in the Schematic-to-Rich condition received a problem consisting of a geometric shape sample and rich choices, and those in the Rich-to-Schematic condition received a problem with a rich object sample and schematic object choices. The experimenter revealed the sample and said, "Look at this picture." Then she showed three options below the sample and said, "Now look at these pictures." She waited approximately 3 s quietly, and then asked, "Which one of these pictures (continuous point to the three options) is the best match to this picture (pointing to the sample)?" In responding to the child's choice, we again followed the procedure of Huttenlocher and Levine (1990)'s test. That is, if the child chose the correct match, the experimenter said, "Yes, that is right. This picture (pointing to the correct answer) is the best match to this one (pointing to the target) because this picture goes like this (pointing to the two objects in correct answer sequentially) and this one too goes like this (pointing to the two objects in target sequentially)." If the child chose an incorrect option, the experimenter said, "Actually, this picture is the best match to that one because this picture goes like this (pointing to the two objects of the sample sequentially) and this one too goes like this (pointing to the two objects of the correct match sequentially).” As in the previous study, the experimenter did not mention anything about spatial relations between the objects to investigate how readily young children use the spatial relations for generalization spontaneously.

After the practice trial, the experimenter started the first spatial analogy item on a laptop computer. The instructions were identical to those in the practice trial, but children received no feedback about their answers. “Look at this picture. Then now look at these pictures. (There are three pictures.) Which of these (three) pictures is the best match picture to this picture here? Which one goes best with this picture?” Once the child chose an answer, the experimenter said “OK,” wrote down the child’s response on the recording sheet (as the location of choice, 1, 2, or 3), and moved forward to the next item. If children provided no answer to a question, the experimenter could repeate the question only once. This test took approximately 5 to 8 minutes to complete.

After completing the Spatial Analogies test, children received a spatial language test. First, the experimenter explained the test to the child. The script was as following: “Now, you will see various shapes here. But I seem to have forgotten all my shape names. Do you think you could help me name these shapes? If you don’t know the name of the shape, it’s OK. Just say “I don’t know” and we will move on to the next one.” The experimenter showed children the shapes one by one and asked, “What’s this?” or “How about this?” Once the child answered, the experimenter said “OK” neutrally or repeated the child’s response, and wrote down the response on the recording sheet. For the shape name comprehension test, the script was as follows: “So now I’m going to see if you can point to the shape I’m asking for. Can you find the ___?” Next, for the locative term production test, the experimenter said, "Now I'll show you pictures of a bear and a cup. Do you think you could tell me with words where the bear is in relation to the cup?" If children said "right here" or "right there," then the experimenter covered her eyes and said, "What if I cover my eyes? I can't see where the bear is anymore. Can you tell me with words where the bear is?" If they kept saying, "right here", then the experimenter started priming them with "Is it in front of or to the right of the cup?" etc. Once the child produced a preposition word or if they kept saying, "right here/there", the experimenter moved on to the next spatial relation picture. Lastly, in the comprehension of locative terms, the experimenter asked, "Can you point to the picture that matches the closest to what I ask for? In which picture is the bear (or cup) ______(e.g., far away from the cup)?" It took about 10 minutes to finish this test.

Coding

Spatial analogies test. Participants were given 1 point for each item in which they chose the correct spatial relation match. Thus, the total spatial analogies score ranged from 0 to 12 points. The possible analogies score for each relation type (i.e., *on*, *in*, and *above*) ranged from 0 to 4 points.

Spatial language test. Children received 1 point for each question that they named the given shape correctly. In Korean, it is common to use one shape name as a more specific classification of another shape name. For example, a square is a more specific type of a rectangle, which is a more specific type of a parallelogram, which is again a more specific type of a quadrilateral. Korean preschool children are rarely taught the specific names of shapes, such as "rectangle" and "square". Instead, they are taught more general terms such as "neh-mo" which means "four corners." Therefore, preschoolers in the present study often responded with the same shape name “neh-mo” to the various geometric shapes with four angles such as rectangle, square, trapezium, diamond, and parallelogram. Although the answer is technically correct (because they all have four corners), giving 1 point for every “four corners” response seemed inappropriate because more of the older children said “I don’t know” to the items such as trapezium and parallelogram. Possibly, they started to differentiate among those quadrilaterals although they could not provide the corresponding names. Thus, to reflect the true developmental changes in children’s productive shape vocabulary, the following criteria were used for coding: (1) Responding with “four corners” to the trapezium and parallelogram questions received 0 point, as responding with “I don’t know”; (2) Responding with “square” or “four corners” to the square item equally received 1 point because the term “square” is taught in elementary schools in Korea (see Table 2) and the shape is generally taught as “four corners” in preschool education; (3) Responding with “rectangle” or “long four corners”, but not “four corners”, to the rectangle item received 1 point because a rectangle is labeled “long four corner” in some Korean books for preschoolers; and (4) for the same reason, both “oval” and “long circle” received 1 point for the oval question. The possible score maximum for shape name production was 13.

For comprehension of shape names, children received 1 point for each question that they chose the correct shape. The item of “diagonal (dae-gak-seon)” was omitted from coding because it was considered more a directional term rather than a shape name. Consequently, the maximum score possible for this section was 4.

For productive locative terms, only responses including targeted locative terms received 1 point. Targeted locative terms (correct answers) for each item are seen in

Appendix C. They were “behind (dui)”, “below (mit/ ah-rae)”, “in/inside (an/sok/sok-an)”, “under (mit/ ah-rae)”, “in front (ap)”, “above (wi)”, “away, far from (meol-li)”, “between/middle (sa-yi/ ga-woon-deh/ joong-gan)”, and “above (wi)”. One thing to note about coding is that, unlike English, Korean spatial language does not lexically distinguish between *above* and *on* relations, with “wi” referring to both types of spatial relations (see Table 1). Therefore, ‘wi’ response was coded as a correct answer for both questions. The maximum score possible for this section was 8.

Lastly, for the section of locative term comprehension, two items were omitted from coding: The first “upside-down (geo-kku-ro)” question and the “diagonal (dae-gak-seon)” question. The “upside-down” was omitted because the same spatial relation was asked in another item of the section as well; The “diagonal” was omitted because it was not considered as a locative term. Therefore, the maximum score that children could receive in this section was 6.

Korean locative terms	Gloss
안 (ahn) / 속 (sok)	in, inside
위 (wi)	on (top of), above, over
아래 (ah-reh) / 밑 (mit)	under, below
앞 (ap)	in front of
뒤 (dui)	behind, in back of
옆 (yeop)	next to, beside
사이 (sa-yi) / 가운데 (ga-woon-deh)/ 중간 (joong-gan)	in between, in the middle
멀리 (meol-li)	far from
거꾸로 (geo-ku-ro)	upside-down
왼쪽 (yoen-chok)	to the left of
오른쪽 (o-reun-chok)	to the right of

Table 1. Gloss of Korean locative terms.

Korean shape names	Gloss	Elementary School Mathematics Curriculum (2011.8)
dong-gu-ra-mi	round shape	Preschool ~ 1st grade
seh-mo	three corners, triangle	
neh-mo	four corners, quadrangle	
byul	star	
heart	heart	
won	circle	2nd grade
sam-gak-hyung	triangle	
sah-gak-hyung	quadrangle	
oh-gak-hyung	pentagon	
yook-gak-hyung	hexagon	
jik-sa-gak-hyung	rectangle	3rd grade
jeong-sak-gak-hyung	square	
sa-da-ri-kol	ladder shape, trapezium	4th grade
pyung-hang-sa-byun-hyung	parallelogram	
ta-won	oval	
ma-reum-mo	diamond	
ban-won	semicircle	

Table 2. Gloss of Korean shape names and inclusion in Korean Elementary School Mathematics Curriculum (2011.8)

Results

Preliminary analyses. We first conducted a set of analyses to ensure that children in each condition did not differ significantly in age or spatial language. With respect to child age, the two conditions did not differ significantly in age in months (see Table 3 for the means and standard deviations of age).

Spatial vocabulary. To ensure that there were no differences in the spatial language skills of the children, we conducted a 2 (Condition: Schematic-to-Rich vs. Rich-to-Schematic) × 3 (Age: 3- vs. 4- vs. 5-year-olds) analysis of variance (ANOVA) on each of the production and comprehension of shape names and locative terms. None of the four ANOVAs yielded any significant effects of condition, failing to show that children differed in their spatial language skills across condition. However, these ANOVAs did yield significant effects of child age. Children at each age differed significantly in their naming of shapes, F (2, 110) = 13.73, $p < .001$, $\eta_p^2 = .20$. Post-hoc multiple comparisons using Tukey's HSD revealed that 5-year-old children (M = 6.53, SD = 1.41) tended to produce more shape names than 4-year-old children (M = 5.90, SD = 1.19) although the difference did not reach significance (p = .059). Five- and 4-year-old children each produced significantly more shape names than 3-year-olds (M = 5.08, SD = 0.94, $p < .001$ and $p < .01$, respectively). The age effect was also significant for children's comprehension of shape names, F (2, 95) = 17. 76, $p < .001$, $\eta_p^2 = .27$. Five-year-olds comprehended significantly more shape names (M = 3.00, SD = 1.15) than 4-year-olds (M = 2.20, SD = 1.26) ($p < .05$), who comprehended significantly more shape names than 3-year-olds (M = 1.33, SD = 0.99) ($p < .01$). Recall that our shape name comprehension test presented only four geometric shapes. The ANOVAs also yielded significant effects of age for children's naming of locative terms, F (2, 109) = 18.41, $p < .001$, $\eta_p^2 = .25$, and their comprehension of locative terms, F (2, 109) = 8.69, $p < .001$, $\eta_p^2 = .14$. Five-year-olds produced more locative terms than 4-year-olds (M = 6.00, SD = 1.25, M = 4.49, SD = 2.29, respectively; $p < .01$), who produced more locative terms than 3-year-olds (M = 3.32, SD = 1.99; $p < .05$). With comprehension, 5-year-olds comprehended more locative terms than 4-year-olds (M = 5.26, SD = 0.76, M = 4.51, SD = 1.07, respectively; $p < .01$) and 3 year olds (M = 4.29, SD = 1.27, $p < .001$), who did not differ significantly from each other in comprehensive locative terms (p = .63). In this test, we assessed comprehension of 6 locative terms. In sum, all of the spatial vocabulary skills tested differed across age, but not across condition.

Condition	Age Group	Mean age (mos.)	Age range (mos.)	Shape names		Locative terms	
				Production	Comprehension	Production	Comprehension
Schematic-to-Rich	3 yrs.	43.9 (2.50)	37.8-47.9	5.39 (0.92)	1.38 (0.96)	3.61 (2.06)	4.28 (1.23)
	4 yrs.	53.6 (3.67)	48.3-59.1	5.90 (1.29)	2.06 (1.26)	4.35 (2.37)	4.35 (2.37)
	5 yrs.	66.0 (3.79)	60.1-71.9	6.40 (1.31)	3.20 (0.86)	6.20 (1.20)	5.25 (0.64)
Rich-to-Schematic	3 yrs.	43.7 (2.60)	39.8-47.9	4.80 (0.90)	1.29 (1.05)	3.05 (1.93)	4.30 (1.34)
	4 yrs.	54.7 (3.32)	49.3-59.8	5.90 (1.12)	2.35 (1.27)	4.63 (2.27)	4.68 (1.06)
	5 yrs.	66.2 (4.41)	60.5-76.0	6.59 (1.54)	2.82 (1.38)	5.71 (1.31)	5.24 (0.90)

Table 3. Children's age in months and scores on the Spatial Vocabulary Test by condition and age in Study 1. Note. Comprehension is lower then production in this table because the Comprehension section had fewer questions than the Production section for the Shape Name part in the spatial vocabulary test. That is, the numbers in the Table do *not* represent the total number of shape names that children were actually able to understand.

Performance on spatial analogies test. Next we examined children's performance on the spatial analogies test. Table 4 shows the means and standard deviations of the spatial analogy scores (i.e., number of items in which children chose a correct spatial relation match) by age, condition, and target spatial relation. We first compared performance to chance, and then compared the effects of age, target relation, and object type on performance.

Age Condition	Study 1 (Cross-Type Generalization) Above	 On	 In	 Total
3 years				
Schematic-to-Rich	1.05 (.95)	1.40 (.94)	1.85 * (.88)	4.30 (1.69)
Rich-to-Schematic	1.10 (1.12)	1.25 (.64)	1.10 (.91)	3.35 * (1.35)
Total	1.08 (1.02)	1.33 (0.80)	1.48 (0.96)	3.83(1.58)
4 years				
Schematic-to-Rich	2.05 *(1.32)	2.20**(1.06)	2.05** (1.00)	6.30 ** (2.81)
Rich-to-Schematic	1.55 (1.15)	1.70 (1.38)	1.50 (0.95)	4.75 (2.15)
Total	1.80* (1.24)	1.95**(1.24)	1.78** (1.00)	5.53** (2.59)
5 years				
Schematic-to-Rich	2.80***(1.28)	2.80***(1.06)	2.75*** (0.97)	8.35*** (2.70)
Rich-to-Schematic	2.45*** (1.28)	2.55*** (1.05)	1.85 * (1.04)	6.85*** (2.54)
Total	2.63***(1.28)	2.68***(1.05)	2.30*** (1.09)	7.60***(2.70)

Table 4. Descriptive statistics of spatial analogy scores in Study 1. The scores indicate the number of items where children chose correct options. Scores ranged from 0 to 4 for each relation type (*above*, *on*, and *in*), and from 0 to 12 for the total score (relation types combined). Asterisk marks significant difference from the chance score. Chance score for each relation type equals 1.33, and chance score for Total equals 4.0.
*$p < .05$. **$p < .01$. ***$p < .001$.

(1) Comparison to chance. Since there were three options to choose in each spatial analogy item, the chance that children would choose the correct option from random answering was 0.33. Out of 12 spatial analogy items, the mean score (number of correct responses) that would be expected if they chose responses randomly was 4. One-sample t-tests ($p < .05$; two-tailed) were used to compare children's mean scores to the mean chance score (that is, 4). Overall, when the data were collapsed across condition and spatial relation, 3-year-old children's performance did not differ significantly from the chance score, t (39) = 0.70, p = .49. On average, they were accurate in 3.83 items out of 12 items (SD = 1.58), indicating that overall they did not generalize the spatial relations. Four-year-old children's performance, however, did differ significantly from chance, t (39)= 3.72, p = .001, with the average accuracy of 5.53 items out of 12 (SD = 2.59). Five-year-old children also performed above chance, t (39) = 8.24, p < .001, choosing the accurate option in 7.43 items out of 12 (SD = 2.63). We also conducted comparisons to chance by condition and spatial relation. The results are marked in Table 4 with an asterisk denoting a significant difference from the chance (p < .05, two-tailed). As shown in Table 4, 5-year-old children performed above chance in both conditions, whereas 4-year-old children performed above chance only in the Schematic-to-Rich condition. Further, it was only on the containment items in the Schematic-to-Rich condition that 3-year-old children performed above chance. Three-year-old children's performance in the Rich-to-Schematic condition was significantly below chance.

(2) The effects of object type, target relation, and age. Next, we assessed the effects of child age, target relation, and type of objects on children's performance on the spatial analogies test. Because spatial vocabulary has been linked to spatial skills, we included spatial vocabulary as a covariate in the analyses. To capture both comprehension and production of the two aspects of spatial language (i.e., shape names and locative terms), we created a composite of spatial vocabulary by summing across the four measures in the spatial language tests. Spatial analogy scores was submitted to a 2 (Condition: Schematic-to-Rich vs. Rich-to-Schematic) × 3 (Age: 3 years vs. 4 years vs. 5 years) × 3 (Target relation: above, on, and in) mixed-model analysis of covariance

(ANCOVA) with spatial vocabulary composite as a covariate. This analysis indicated that spatial vocabulary composite was a significant covariate, F (1, 94) = 5.99, $p < .05$, $\eta_p^2 = .06$. The analysis also yielded significant main effects for condition, F (1, 94) = 8.35, $p < .01$, $\eta_p^2 = .08$, and age, F (2, 94) = 8.38, $p < .001$, $\eta_p^2 = .15$. There were no other significant effects. As shown in Figure 3, Children in the Schematic-to-Rich condition showed significantly more accurate performance (M = 6.32, SD = 2.93) than those in the Rich-to-Schematic condition (M = 4.98, SD = 2.50) regardless of age or spatial relation. In addition, post-hoc multiple comparisons using Bonferroni corrections revealed that 5-year-old children (M = 7.6, SD = 2.7) performed significantly more accurately than 4-year-old children (M = 5.53, SD = 2.59), $p < .05$, who also performed significantly more accurately than 3-year-old children (M = 3.83, SD = 1.58), $p < .05$.

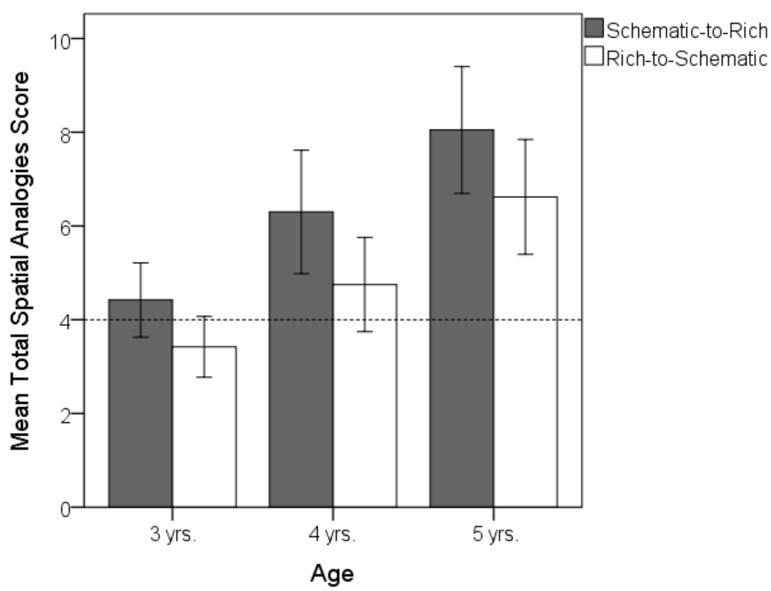


Figure 3. Mean number of correct responses on the spatial analogies test by 3-, 4-, and 5-year-old children in each condition in Study 1. Possible scores ranged from 0 to 12. Chance performance equals four correct responses. Dotted line indicates mean chance performance. Error bars represent the 95% Confidence Intervals of the means.

Age	Study 1 (Cross-Type Generalization)			
Condition	Above	On	In	Total
3 years				
Schematic-to-Rich	5 (25%)	10 (50%)	13 (65%)	11 (55%)
Rich-to-Schematic	7 (35%)	5 (25%)	5 (25%)	4 (20%)
Total	12 (30%)	15 (37.5%)	18 (45%)	15 (37.5%)
4 years				
Schematic-to-Rich	11 (55%)	15 (75%)	12 (60%)	14 (70%)
Rich-to-Schematic	9 (45%)	11 (55%)	10 (50%)	11 (55%)
Total	20 (50%)	26 (65%)	22 (55%)	25 (62.5%)
5 years				
Schematic-to-Rich	17 (85%)	17 (85%)	18 (90%)	18 (90%)
Rich-to-Schematic	16 (80%)	17 (85%)	10 (50%)	15 (75%)
Total	33 (82.5%)	34 (85%)	28 (70%)	33 (82.5%)

Table 5. Number and proportion of children who chose the spatial relation match more frequently than mean chance score, per age, condition, and target relation type in Study 1.

These patterns of results observed with averages also emerged when we considered the number of children whose spatial analogy scores were higher than the mean chance score (that is 4). Table 5 shows the number and proportion of children who chose the spatial relation match on more than four items, per age, condition, and target relation type. A significant relationship was found between age and number of children who performed above the mean chance score, χ^2 (2, N = 120) = 17.07, p < .001. More 5-year-old children (82.5%) performed above the mean chance score—choosing the correct spatial match on 8.42 out of 12 items— than 4-year-old children (62.6%) and 3-year-old children (37.4%). Also, there was a significant relationship between condition and number of children who performed above the mean chance score. Across age groups, more children in the Schematic-to-Rich condition (71.7%) chose the correct spatial relation match than in the Rich-to-Schematic condition (50%), χ^2 (1, N = 120) = 5.91, p < .05. Thus, the results of the individual analysis mirrored the group findings.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.54**	—				
3. Shape name composite	.87**	.88**	—			
4. Locative term comprehension	.49**	.37**	.51**	—		
5. Locative term production	.60**	.51**	.65**	.61**	—	
6. Locative term composite	.62**	.51**	.67**	.82**	.96**	—
7. Age (mos.)	.58***	.49***	.62***	.41**	.54 **	.55 **

Table 6. Correlations between age and spatial vocabulary variables.

The relation between spatial analogy performance and spatial vocabulary. Next we examined associations of performance on the spatial analogies test with children's spatial vocabulary variables (production and comprehension of shape names and locative terms). First, our data revealed that children's age in months was strongly associated with their spatial analogy score, r (118) = .55, p < .001, as well as the spatial vocabulary measures (see Table 6 for the complete correlations). Therefore, a partial correlation analysis was conducted with children's age in month partialled out. It revealed that children's spatial analogy performance significantly correlated with production of locative terms, r (97) = .23, $p < .05$, and locative term composite, r (97) = .23, $p < .05$. However, no significant correlation was found between spatial analogy performance and comprehension of locative terms, $p = .23$, or any of the shape vocabulary measures, *p*s > .39.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.34***	—				
3. Shape name composite	.80***	.83***	—			
4. Locative term comprehension	.35***	.27**	.38**	—		
5. Locative term production	.44***	.38***	.50***	.50***	—	
6. Locative term composite	.47***	.39***	.52***	.77**	.94**	—
7. Spatial Analogy	.08	.12	.12	.14	.23 *	.23 *

Table 7. Partial correlations between spatial analogy performance and spatial vocabulary variables. $df = 98$. Two-tailed. $^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Discussion

The results from this first study clearly show developmental changes in the ability to transfer spatial relations across object type during the preschool years. Overall, 3-year-old children failed to generalize the spatial relations across object type, as evidenced by their performance at chance level. In addition, their failure to make cross-type transfer was observed in both directions of transfer, namely, the transfer from rich objects to schematic objects and the transfer from schematic objects to rich objects. These results suggest that it is challenging for 3-year-old children to spontaneously detect common spatial arrangement between instances consisting of different types of objects (geometric shapes and actual objects in the present case). This challenge is, however, alleviated to some extent by the age of 4, as four-year-old children can generalize the spatial relations, especially from schematic objects to rich objects. Furthermore, by 5 years of age, the ability to detect common spatial relations between different types of objects becomes more robust, as indicated by their above-chance performance in both directions of transfer. Also, the ANCOVA results show that this age-related improvement occurs regardless of target spatial relation or direction of cross-type transfer.

Most importantly, the results indicate that preschoolers' generalization of spatial relations occurs more successfully from schematic objects to rich objects than vice versa, as indicated by the significant effect of condition. Particularly, this effect was not qualified by child age or relation type, demonstrating that the advantage of schematic depictions in cross-type transfer existed regardless of the ages and spatial relations tested. This finding is akin to previous findings in object categorization showing the asymmetry in transfer between simplified objects and richly detailed objects (Son, Smith, & Goldstone, 2008). Just as children are more likely to generalize a category label learned with simplified objects to richly detailed objects than vice versa, children are more likely to generalize a spatial relation depicted with schematic objects (i.e., geometric shapes) to an instance consisting of richer objects than the other way around. The finding is also in line with previous findings showing that knowledge that children acquired from solving relational problems with geometric shapes was transferred to later solving relational problems with rich, familiar objects, but the converse was not the case (Kaminski & Sloutsky, 2010). Further, the results fit well with the idea that simplified objects are more likely to be considered to refer to something else than more detailed objects (e.g., Kaminski, Sloutsky, & Heckler, 2008; Uttal et al., 2013) and the suggestion that a simplified instance functions as a model of diverse rich instances (Son, Smith, & Goldstone, 2011). However, the results are also predicted by the argument that a simplified instance offers an advantage because it shortcuts the abstraction process (Son, Smith, & Goldstone, 2008) or because it is less likely to make the objects interesting in their own right, thus shifting less cognitive resources to the objects themselves rather than the relation between the objects (e.g., Rattermann, Gentner, & DeLoache, 1990; also see DeLoache, 1987 and Uttal, Scudder, & DeLoache, 1997 for a similar discussion). Hence, the mechanisms underlying the advantage of schematic depictions in cross-type generalization cannot be known from the present results.

The results from Study 1 also indicate that the containment (*in*), support (*on*), and *above* relations did not vary in how easily young children generalized them across object type. The lack of spatial relation effect differs from the findings in infant spatial categorization research as well as children's bias in preposition acquisition, communication of spatial relations, and construction of spatial relations. Nonetheless, it is noteworthy that 3-year-old children performed above chance only with the containment relations in the Schematic-to-Rich condition. This result suggests that containment relations might be slightly more accessible to the youngest preschool children relative to the other relations.

Lastly, our results from Study 1 demonstrate that young children's cross-type spatial analogy skill is linked to their ability to name spatial locations of objects. In contrast, their naming or understanding of shape names, or their understanding of locative terms were not linked to children's performance on the cross-type spatial analogies test when age was controlled for. Hence, the results provide support for a more intimate link between generalization of spatial relations and acquisition of locative terms. The finding is also connected with previous findings showing that particular aspects of spatial language, aspects that are directly relevant to solving a given spatial task, are more strongly associated with a particular spatial reasoning skill than other aspects (Hermer-Vazquez, Moffet, & Munkholm, 2001; Pyers et al., 2010; Simms & Gentner, 2008).

CHAPTER 3

STUDY 2

Study 1 revealed an asymmetry in children's generalization of spatial relations when transfer is made across object type. One interpretation of this asymmetry is that a schematic sample promotes transfer of spatial relations better in comparison to a rich sample. However, the conditions in Study 1 differed not only in sample type but also the type of options. Consequently, it is unclear whether the benefit of the Schematic-to-Rich condition is due to the simplicity of the sample, the richness of the options, or combination of the two. One way to examine this issue is to test children's spatial analogy in the Rich-to-Rich condition and Schematic-to-Schematic condition. Testing such conditions will allow us to determine whether the simplicity of the sample offers an advantage (e.g., comparison of Rich-to-Rich versus Schematic-to-Rich conditions) as well as whether rich options are beneficial (e.g., comparison of Schematic-to-Rich versus Schematic-to-Schematic conditions). Furthermore, we can determine whether schematic objects better promote within-type transfer, where spatial relations are generalized between similar types of objects. Therefore, we investigated children's within-type generalization of spatial relations in Study 2.

Method

Participants

Participants were 121 children in three age groups: 40 three-year-old, 40 four-year-old, and 41 five-year-old children. There were an equal number of male and female children for the 3- and 4-year-olds' groups. There were 21 male and 20 female children for the 5-year-olds' group. One additional 5-year-old child participated but was excluded for refusing to answer questions. Children were recruited in the same manner as in Study 1 from the same eight childcare centers in Seoul, Korea. Children's socioeconomic backgrounds varied within the more general middle class, although not formally assessed. Korean was the primary language spoken at home for all children.

Materials

Spatial analogies test. Two sets of spatial analogy items, Rich-to-Rich and Schematic-to-Schematic were constructed by cross combining the samples and options of the two sets of spatial analogies test used in Study 1. That is, the Rich-to-Rich set in Study 2 was made by combining each sample of the Rich-to-Schematic condition with each set of options of the Schematic-to-Rich condition in Study 1. Likewise, the Schematic-to-Schematic set was made by combining each sample of the Schematic-to-Rich condition with each set of options of the Rich-to-Schematic condition in Study 1. The two sets matched with respect to the arrangement of spatial relations. As in Study 1, the spatial analogy items were created on Microsoft PowerPoint 2011 slides. The picture size was the same as in Study 1. Again, three presentation orders were created.

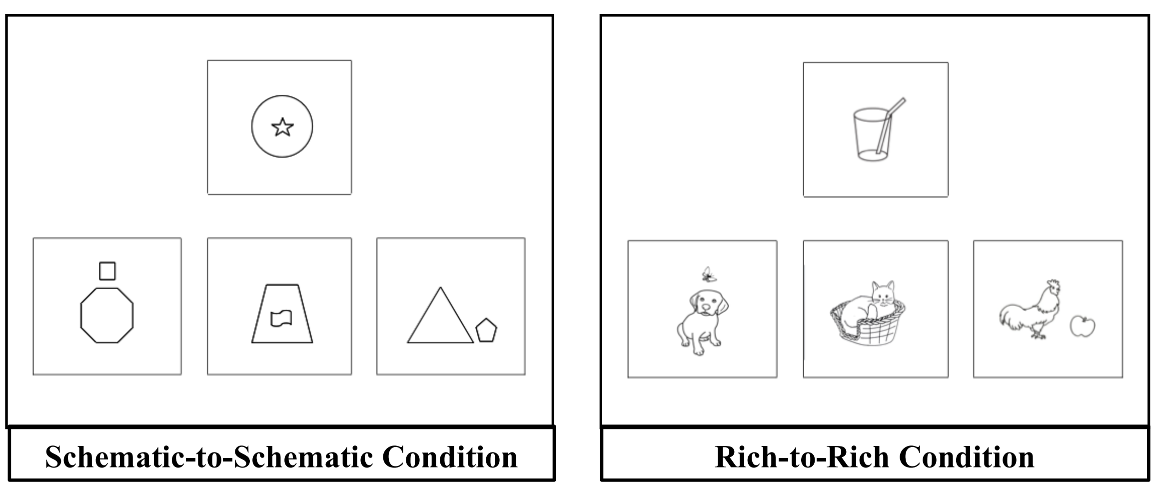


Figure 4. Sample spatial analogy items in conditions of Study 2. See Appendix A for a complete list of spatial analogy items used in the present research.

Spatial language test. The same measure of spatial vocabulary from Study 1 was used in the present study.

Procedures & Coding

The procedure and coding were identical to those used in Study 1.

Results

Preliminary analyses. As was the case in Study 1, children in the two conditions did not differ in age in months. The ranges, means, and standard deviations of this variable are shown in Table 8.

Condition	Age group	Mean age (mos.)	Age range (mos.)	Shape names		Locative terms	
				Production	Comprehension	Production	Comprehension
Schematic-to-Schematic	3 yrs.	44.6 (2.13)	39.9-47.9	5.00 (1.41)	1.50 (1.15)	3.16 (1.77)	3.58 (1.35)
	4 yrs.	54.7 (2.68)	49.8-59.1	5.79 (1.08)	2.16 (1.46)	5.21 (1.55)	4.63 (0.90)
	5 yrs.	66.9 (3.34)	61.2-72.3	6.84 (1.64)	2.67 (1.24)	6.11 (0.90)	5.33 (0.69)
Rich-to-Rich	3 yrs.	44.6 (2.67)	37.1-47.9	4.90 (1.17)	1.10 (1.21)	3.25 (1.74)	3.85 (1.35)
	4 yrs.	53.6 (3.78)	48.1-59.5	5.70 (0.92)	2.17 (0.71)	4.45 (1.96)	4.85 (0.37)
	5 yrs.	66.3 (3.50)	60.1-71.9	6.50 (0.86)	2.93 (0.70)	6.22 (0.62)	5.17 (0.62)

Table 8. Children's age in months and scores on the Spatial Vocabulary Test by condition and age in Study 2. Note. Again, comprehension is lower than production because the Comprehension section had fewer questions than the Production section for Shape Names in the spatial vocabulary test. That is, the numbers in the Table do *not* represent the total number of shape names that children could understand.

Spatial vocabulary. The means and standard deviations of spatial language skills by age and condition are shown in Table 8. To ensure that there were no differences in the spatial vocabulary of the children across condition, a 2 (Condition) × 3 (Age) ANOVA was performed on each spatial vocabulary measure. Again, none of the four ANOVAs yielded any significant effects of condition, failing to show that children differed in their spatial vocabulary across condition. However, these ANOVAs did yield significant effects of child age. Children at each age differed significantly in their naming of shapes, F (2, 109) = 19.14, $p < .001$, $\eta_p^2 = .27$. Post-hoc comparisons using Tukey's HSD showed that 5-year-olds produced significantly more shape names than 4-year-olds ($p < .01$), who produced significantly more shape names than 3-year-olds ($p < .05$). Child age effect was also significant for children's comprehension of shape names, F (2, 109) = 15.74, $p < .001$, $\eta_p^2 = .24$. Five- and four-year-olds did not differ significantly from one another in the number of shape names comprehended ($p = .059$), but each was significantly higher than 3-year-olds ($p < .001$, $p < .01$, respectively). The ANOVAs also yielded significant effects of age for children's naming of locative terms, F (2, 108) = 34.43, $p < .001$, $\eta_p^2 = .39$, and their comprehension of locative terms, F (2, 108) = 23.33, $p < .001$, $\eta_p^2 = .32$. Five-year-olds produced more locative terms than 4-year-olds (p = .001), who produced more locative terms than 3-year-olds ($p < .001$). With comprehension, 5-year-olds and 4-year-olds did not differ significantly from one another ($p = .061$), but each comprehended more locative terms than 3-year-olds (ps < .001). In sum, the spatial language skills tested did not differ across condition, but did differ across age, with production significantly increasing at each age and comprehension between the ages of 3 and 4 years.

Age	Study 2 (Within-Type Generalization)			
Condition	Above	On	In	Total
3 years				
Schematic-to-Schematic	1.35 (1.14)	1.65 (1.18)	1.65 (1.00)	4.65 (2.62)
Rich-to-Rich	0.85 * (0.75)	1.65 (0.93)	2.15 * (0.88)	4.65 (1.57)
Total	1.10 (0.98)	1.65 (1.05)	1.90 *** (0.96)	4.65 (2.13)
4 years				
Schematic-to-Schematic	2.40 * (1.14)	2.60 * (1.27)	2.65 * (1.31)	7.65 * (3.18)
Rich-to-Rich	2.45 * (1.15)	1.95 * (0.89)	2.35 * (0.93)	6.75 * (2.15)
Total	2.43*** (1.13)	2.28 *** (1.13)	2.50 *** (1.13)	7.20 ***(2.72)
5 years				
Schematic-to-Schematic	3.45 * (0.83)	3.55 * (0.69)	3.75 * (0.55)	10.48 *(2.21)
Rich-to-Rich	1.75 (1.33)	1.90 * (0.85)	2.40 * (1.14)	6.05 * (2.70)
Total	2.54*** (1.43)	2.73 *** (1.12)	3.05 *** (1.12)	8.32 ***(3.31)

Table 9. Descriptive statistics of spatial analogy scores in Study 2. The scores indicate the number of items where children chose correct options. Scores ranged from 0 to 4 for each relation type (*above*, *on*, and *in*), and from 0 to 12 for the total score (relation types combined). Asterisk marks significant difference from the chance score. Chance score for each relation type equals 1.33, and chance score for Total equals 4.0.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

Performance on spatial analogies test. Next, we examined children's performance on the spatial analogies test. Table 9 shows the means and standard deviations of the spatial analogy scores by age, condition, and target relation.

(1) Comparison to chance. As in Study 1, we first determined whether children tended to select the accurate spatial relation match at each age. Children's scores on the spatial analogies test were analyzed in comparison to a mean chance score (that is, 4), using one-sample t-tests. When the condition and spatial relation variables were collapsed, 3-year-old children's performance (M = 4.65 items, SD = 2.13) did not differ significantly from chance performance, t (39) = 1.93, p = .061. Four-year-old children's performance, however, did differ significantly from chance, t (39) = 7.44, p < .001, with the mean score of 7.20 (SD = 2.72). Five-year-old children also performed above chance, t (40) = 8.36, p < .001, choosing the accurate spatial match in 8.32 items (SD = 3.31). We also conducted comparisons to chance by condition and target spatial relation. The results are presented in Table 9, with an asterisk denoting a significant difference from chance performance (p < .05, two-tailed). Three-year-old children, despite their overall performance at chance level, performed above chance on the containment items, especially in the Rich-to-Rich condition. Interestingly, their performance was below chance on the *above* items in the Rich-to-Rich condition. In sum, in this within-type spatial analogies test, 4- and 5-year-old children tended to select the accurate spatial relation match, but 3-year-old children did not.

(2) The effects of object type, target relation, and age. Next, we assessed the effects of object type, spatial relation, and age on children's performance on the spatial analogies test. As in Study 1, we controlled for children's spatial vocabulary in this analysis. Children's spatial analogy scores (the number of trials in which children chose a correct spatial relation match) were submitted to a 2 (Condition: Schematic-to-Schematic vs. Rich-to-Rich) × 3 (Age: 3 years vs. 4 years vs. 5 years) × 3 (Spatial relation: above, on, and in) repeated measures ANCOVA, with spatial vocabulary composite entered as a covariate. This analysis revealed that the spatial vocabulary composite was a significant covariate, F (1, 101) = 7.16, p < .01, η_p^2 = .07. The analysis also yielded significant main effects of age, F (2, 101) = 3.78, $p < .05$, $\eta_p^2 = .07$, and condition, F (1, 101) = 10.91, p = .001, $\eta_p^2 = .10$, as well as a significant age × condition interaction, F (2, 101) = 7.60, p = .001, $\eta_p^2 = .13$. These effects were, however, qualified by a significant spatial relation × condition × age interaction, F (4, 202) = 3.14, $p < .05$, $\eta_p^2 = .06$, indicating that the condition × spatial relation interaction differed with child age.

Further analyses were used to examine the significant three-way interaction revealed in the omnibus ANCOVA. A 2 (Condition: Schematic-to-Schematic vs. Rich-to-Rich) × 3 (Spatial relation: above, on, and in) ANCOVA with the spatial vocabulary composite as a covariate was performed for each age group. For the 3-year-old children, spatial vocabulary composite was a significant covariate, F (1, 35) = 5.86, $p < .05$, $\eta_p^2 =$ .14. The analysis yielded a significant main effect of spatial relation, F (2, 70) = 3.99, $p <$ .05, $\eta_p^2 = .10$, and a significant spatial relation × condition interaction, F (2, 70 = 4.43, p < .05, $\eta_p^2 = .11$, indicating that the effect of spatial relation varied with condition (i.e., object type). A one-way repeated-measures ANCOVA with spatial relation as an independent variable and spatial vocabulary composite as a covariate was performed for each condition. In the Schematic-to-Schematic condition, the spatial vocabulary composite was a significant covariate, F (1, 16) = 4.62, $p < .05$, $\eta_p^2 = .22$, but there was no effect of spatial relation, indicating that 3-year-old children performed equally across target spatial relation in the Schematic-to-Schematic generalization. In the Rich-to-Rich condition for three-year-old children, spatial vocabulary was not a significant covariate, but the spatial relation effect was significant, F (2, 38) = 12.51, $p < .001$, $\eta_p^2 = .40$. Pairwise comparisons using Bonferroni corrections revealed that 3-year-olds' performance was significantly less accurate on the *above* items (M = 0.85 out of 4, SD =

0.75) than the *in* items (M = 2.15 out of 4, SD = 0.88) and the *on* items (M = 1.65 out of 4, SD = 0.93) ($p < .001$, $p < .05$ respectively), each of which did not significantly differ one another. Thus, 3-year-olds' performance with rich objects was significantly worse when the target relation was the *above* relations.

For the 4-year-old children, the 2 (Condition) × 3 (Spatial relation) ANCOVA yielded no significant results at all, indicating that 4-year-old children's performance did not differ significantly across condition or spatial relation. At age 5 years, the analysis yielded a highly significant main effect of condition, F (1, 30) = 20.31, $p < .001$, η_p^2 = .40. Spatial vocabulary was not a significant covariate. On average across spatial relation, 5-year-old children's performance was more accurate in the Schematic-to-Schematic condition (M = 3.49 out of 4, SD = 0.73) than in the Rich-to-Rich condition (M = 2.02, SD = 0.90).

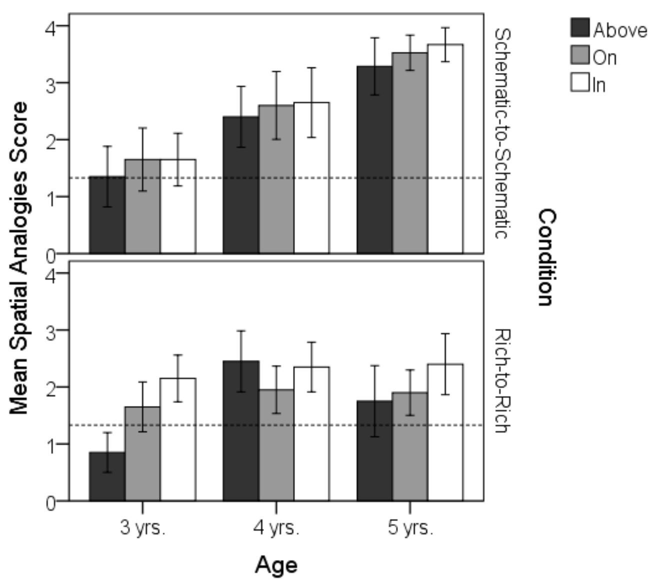


Figure 5. Mean number of correct responses on the spatial analogies test by target spatial relation, age, and condition in Study 2. For each target relation, possible scores ranged from 0 to 4. Chance performance equals 1.33. Dotted line indicates mean chance performance. Error bars represent the 95% Confidence Intervals of the means.

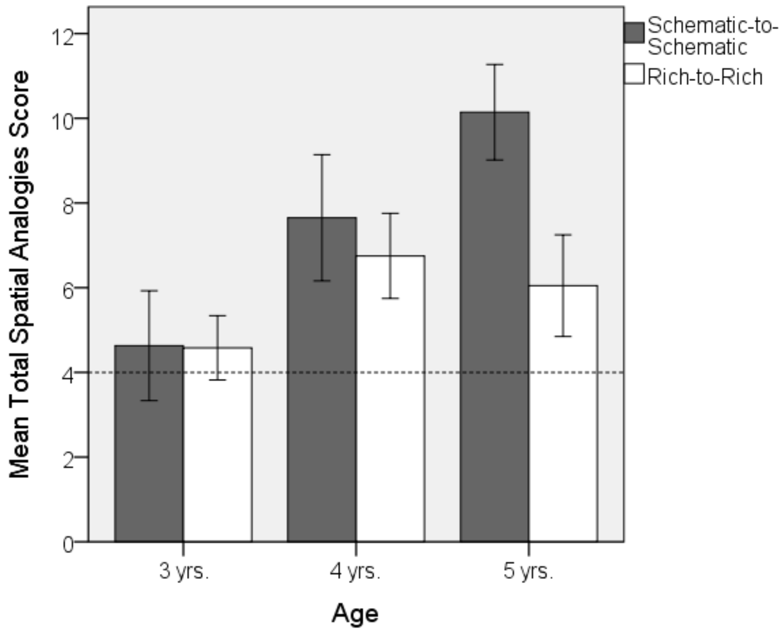


Figure 6. Mean number of correct responses on the spatial analogies test by age and condition in Study 2 when spatial relations combined. Possible scores ranged from 0 to 12. Chance performance equals 4. Dotted line indicates mean chance performance. Error bars represent the 95% Confidence Intervals of the means.

Analyses of number of children whose spatial analogy score was higher than the mean chance score again mirrored the patterns of results observed with averages. Not across age, but only for 5-year-old children, there was a significant relationship between condition and the number of children scoring above the mean chance score, χ^2 (2, N = 120) = 17.07, $p < .001$. More children in the Schematic-to-Schematic condition (71.7%) accurately answered more than 4 items than in the Rich-to-Rich condition (50%), χ^2 (1, n = 120) = 5.91, $p < .05$. For 4-year-old children and 3-year-old children, there was no relationship between performance and condition.

Age	Study 2 (Within-Type Generalization)			
Condition	Above	On	In	Total
3 years (n=40)				
Schematic-to-Schematic	8 (40%)	8 (40%)	10 (50%)	8 (40%)
Rich-to-Rich	4 (20%)	10 (50%)	17 (85%)	10 (50%)
Total	12 (30%)	18 (45%)	27 67.5%)	18 (45%)
4 years (n=40)				
Schematic-to-Schematic	15 (75%)	17 (85%)	14 (70%)	14 (70%)
Rich-to-Rich	17 (85%)	14 (70%)	18 (90%)	18 (90%)
Total	32 (80%)	31 (77.5%)	32 (80%)	32 (80%)
5 years (n=41)				
Schematic-to-Schematic	20 (95.2%)	21 (100%)	21 (100%)	21 (100%)
Rich-to-Rich	9 (45%)	12 (60%)	17 (85%)	14 (70%)
Total	29 (70.7%)	33 (80.5%)	38 (92.7%)	35(85.4%)

Table 10. Number and proportion of children who chose the spatial relation match more frequently than chance, per age, condition, and target relation type in Study 2.

The relation between spatial analogy performance and spatial vocabulary. We also examined associations between children's spatial vocabulary and their performance on the within-type spatial analogies test. A partial correlation analysis that controlled for children's age in months yielded only one significant correlation, a correlation between children's comprehension of locative terms and their spatial analogy score, r (105) = .22, p < .05. That is, children's production of locative terms and their comprehension and production of shape names did not correlate with children's performance on the spatial analogies test once age was controlled for.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.55***	—				
3. Locative term comprehension	.32**	.36***	—			
4. Locative term production	.42***	.51***	.55***	—		
5. Age (mos.)	.52***	.51***	.52***	.65***	—	

Table 11. Correlations between spatial language variables and age of children in Study 2.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.37***	—				
3. Shape name composite	.81***	.84***	—			
4. Locative term comprehension	.05	.17	.13	—		
5. Locative term production	.14	.27**	.25*	.34***	—	
6. Locative term composite	.12	.27**	.24*	.72***	.90***	—
7. Spatial Analogy	.19[a]	.13	.19[a]	.22*	.12	.19 *

Table12. Partial correlations between spatial language variables and spatial analogy of children in Study 2. *df* = 105. Two tailed. *p < .05. **p <.01. ***p < .001. a: marginal, p =.051.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.41**	—				
3. Shape name composite	.82***	.86***	—			
4. Locative term comprehension	.15	.21	.22	—		
5. Locative term production	.23	.27[a]	.30*	.46**	—	
6. Locative term composite	.23	.29*	.31*	.79***	.91***	—
7. Spatial Analogy	.26[b]	.23	.29*	.36**	.18	.29*

Table 13. Partial correlations for Schematic-to-Schematic condition. *df* = 52. a, b: $p < .06$.

	1	2	3	4	5	6
1. Shape name comprehension	—					
2. Shape name production	.28*	—				
3. Shape name composite	.79***	.81***	—			
4. Locative term comprehension	-.09	.12	.02	—		
5. Locative term production	.02	.28*	.19	.24	—	
6. Locative term composite	-.02	.27*	.16	.65***	.90***	—
7. Spatial Analogy	.22	-.03	.12	.08	.07	.09

Table 14. Partial correlations for Rich-to-Rich condition. *df*= 50.

Additional analyses of data from Studies 1 and 2 combined. In Studies 1 and 2, we contrasted rich depictions with schematic depictions in promoting transfer when the similarity distance between the sample and the choices was constant across condition. Additional analyses were performed to further explore whether children's performance differs between within-type transfer and cross-type transfer when either the sample or the choice is fixed. These analyses would provide information about which type of depiction is more facilitative in generalization, given the type of sample or choice.

(1) Comparison of sample types, about how well they are transferred to rich instances. Do sample types differ in how easily they are transferred to rich instances? Kaminski et al. (2008) conducted this comparison and found that learning one example consisting of geometric symbols is much better in promoting transfer of a novel math rule to a situation consisting of rich objects than learning one, two, or three examples consisting of rich objects. This question was worth exploring as many real-world problems (instances) involve perceptually rich objects. To answer this question, children's performance in the Schematic-to-Rich condition and the Rich-to-Rich condition was submitted to a 2 (Sample type: Schematic vs. Rich) × 3 (Age: 3 years vs. 4 years vs. 5 years) × 3 (Relation: above, on, and in) mixed-model ANOVA because the ANCOVA for this comparison indicated that the spatial vocabulary was not a significant covariate and thus, an ANCOVA was not necessary. It yielded a significant Sample type × Age interaction, F (2, 114) = 4.50, $p < .05$, $\eta_p^2 = .07$, indicating that the effect of Sample type differed with child age. In addition, there were significant main effects of Relation, F (2, 228) = 8.4, $p < .001$, $\eta_p^2 = .07$, and Age, F (2,114) = 14.90, $p < .001$, $\eta_p^2 =$ .21, which were qualified by a significant Relation × Age interaction, F (4, 228) = 4.80, p

$= .001, \eta_p^2 = .08$.

To interpret the significant Sample type × Age interaction, a univariate one-way ANOVA with Sample type as the between-subject factor was performed for each age group. It revealed no significant effect of sample type for 3- and 4-year-olds, indicating that Schematic and Rich samples did not differ in how easily they were transferred to rich instances for the children of 3 years or 4 years. In contrast, the analysis yielded a significant effect of sample type for 5-year-old children, $F\ (1, 38) = 7.24$, $p = .011$, $\eta_p^2 = .16$, demonstrating that schematic samples were more readily transferred to rich instances ($M = 8.35$, $SD = 2.70$) than rich samples ($M = 6.05$, $SD = 2.70$) for the 5-year-old children. Thus, by age 5, children showed pattern of results consistent with the findings by Kaminski et al. (2008) with adult learners: simplified objects become advantageous over rich ones, when a relation is generalized to a rich instance. This finding is also similar to our findings from Study 2 (within-type transfer).

We also explored the significant Relation × Age interaction. One-way repeated measures ANOVA with Relation the within-subject factor was performed for each age group separately. Relation type significantly impacted 3-year-olds' performance, $F\ (2,78) = 14.90$, $p < .001$, $\eta_p^2 = .28$, but not performance of the 4- or 5-year-old children. Pairwise comparisons using Bonferroni corrections demonstrated that 3-year-olds more accurately mapped containment relations ($M = 2.00$ out of 4, $SD = 0.88$) than support ($M = 1.53$, $SD = 0.93$), $p < .05$, or *above* relations ($M = 0.95$, $SD = 0.85$), $p < .001$. They also mapped support relations more accurately than *above* relations, $p < .05$. Thus, when a relation is generalized to a rich instance, only 3-year-old children's performance is influenced by spatial relation type, and demonstrates the advantage of *in* relations.

(2) Comparison of sample types, about how well they are transferred to schematic instances. This time, we asked whether sample types differ in how easily they are generalized to schematic instances. We submitted children's performance in the Schematic-to-Schematic condition and the Rich-to-Schematic condition to a 2 (Sample type: Schematic vs. Rich) × 3 (Age: 3 years vs. 4 years vs. 5 years) × 3 (Relation: above, on, and in) repeated measures ANCOVA with spatial vocabulary as a covariate. It revealed that the spatial vocabulary was a significant covariate. The analysis yielded a significant main effect of Sample type, F (1, 101) = 25.33, $p < .001$, $\eta_p^2 = .20$, and a significant main effect of Age, F (2, 101) = 7.07, $p = .001$, $\eta_p^2 = .12$. Across age, when the spatial relations were generalized to schematic instances, a schematic sample was more effective (M = 7.64, SD = 3.58) than a rich sample (M = 4.87, SD = 2.33). In addition, across sample type and relations, 5-year-olds transferred the spatial relations to schematic instances better (M = 8.54 out of 12, SD = 2.98) than 4-year-olds (M = 6.20, SD = 3.06), $p < .05$, and 3-year-olds (M = 4.00, SD = 2.16), $p <= .001$. Three- and 4-year-olds' transfer to schematic instances did not significantly differ from each other.

(3) Comparison of choice types within schematic sample item. Does children's transfer vary with choice type within sample item? We first compared children's transfer from schematic sample when it was within versus cross generalization. Children's spatial analogy scores in the Schematic-to-Rich and Schematic-to-Schematic conditions were submitted to a 3 (Relation) × 3 (Age) × 2 (Choice type: Schematic vs. Rich) ANCOVA with spatial vocabulary composite as a co-variate. The analysis revealed that spatial vocabulary was a significant covariate. Also, the main effect of age was significant, F (2, 97) = 11.10, $p < .001$, $\eta_p^2 = .19$. Five-year-olds (M = 9.44 out of 12, SD = 2.66) performed higher than 4-year-olds (M = 6.98, SD = 3.04), $p < .001$, who performed higher than 3-year-olds (M = 4.48, SD = 2.18), $p < .001$. Moreover, there was a significant main effect of choice type, F (1,97) = 5.07, $p < .05$, $\eta_p^2 = .05$, demonstrating that children's generalization of spatial relations from the schematic samples significantly differed with type of objects presented as the choices. Children's mapping of spatial relations was significantly better when the choices were schematic (within transfer) (M = 7.64, SD = 3.58) than when they were rich objects (cross transfer) (M =6.32, SD = 2.93), $p < .05$. Thus, Schematic-to-Schematic generalization was easier than generalization from Schematic to Rich objects, and children's ability to generalize spatial relations from Schematic depictions increased at each age.

(4) Comparison of choice types within richer sample item. We next compared children's transfer from rich samples when it was within versus cross generalization in the types of objects. A 3 (Relation) × 3 (Age) × 2 (Choice type: Schematic vs. Rich) ANCOVA was performed on the data from Rich-to-Schematic and Rich-to-Rich conditions. Again, spatial vocabulary composite was a significant covariate. The analysis yielded a significant Relation × Age × Choice type interaction, F (4, 198) = 3.16, $p < .05$, $\eta_p^2 = .06$, in addition to a significant Age × Generalization type interaction, F (2, 99) = 4.03, $p < .05$, $\eta_p^2 = .08$, and a significant Relation × Generalization type interaction, F (2, 198) = 5.26, $p < .01$, $\eta_p^2 = .05$.

To interpret the 3-way interaction, 3 (Relation) × 2 (Choice type: Schematic vs. Richer) ANCOVA was performed for each age separately. For age 3, there was a significant Relation × Choice type interaction, F (2, 68) = 6.35, $p < .01$ A univariate one way ANOVA with choice type the between-subject variable was performed for each spatial relation. The ANOVAs revealed that 3-year-olds' generalization from rich instances differed across choice type only for the containment relations, F (1, 38) = 13.80, $p = .001$, $\eta_p^2 = .27$, but not *above* or *on* relations. Three-year-olds mapped containment relations depicted with rich objects better when the choices too were rich (M = 2.15, SD = 0.88) than when they were schematic (cross transfer) (M = 1.10, SD = 0.91). At the age of 4 years, the analysis yielded a significant main effect of choice type, F (1, 38) = 8.66, $p < .01$, $\eta_p^2 = .19$, demonstrating that 4-year-olds' generalization from rich instances differed across choice type. Similar to 3-year-olds, these children transferred spatial relations from rich samples better when the choices were rich too (M = 6.75, SD = 2.15) than when they were schematic (M = 4.75, SD = 2.15). At age 5, there was a significant Relation × Choice type interaction, F (2, 76) = 7.33, $p = .001$, $\eta_p^2 = .16$. A univariate one way ANOVA with choice type the between-subject variable was performed for each spatial relation. It indicated that choice type impacted 5-year-olds' generalization of containment relations, F (1, 38) = 4.93, $p < .05$, $\eta_p^2 = .12$, but not *above* or *on* relations. Five-year-old children also mapped containment relations better when the choices were rich (M = 2.40, SD = 1.14) than when they were schematic (M = 1.65, SD = 0.99).

Children's errors. Korean spatial language does not lexically distinguish between *on* and *above* relations, with one locative term "wi" referring to both relations. One intriguing question is then whether children chose *on* alternatives (as well as *above* alternatives) when asked to generalize *above* relations, and chose *above* alternatives (as well as *on* alternatives) when asked to generalize *on* relations, in accordance with Korean lexicalization of these relations. To explore this possibility, we examined the distribution of children's errors on the *on* and *above* spatial analogy items that provided both *above* and *on* alternatives. There were four such items (2 *on* and 2 *above*). Children's responses were classified into correct response, incorrect but lexically matching response, and incorrect and lexically not matching response (see Table 15).

Age / Condition	3-year-olds *M (SD)*	4-year-olds *M (SD)*	5-year-olds *M (SD)*
Schematic-to-Schematic			
Correct	0.30 (0.31)	0.55 (0.25)	0.79 (0.28)
Lexical match	0.28 (0.26)	0.30 (0.25)	0.14 (0.19)
No lexical match	0.41 (0.23)	0.15 (0.19)	0.07 (0.14)
Rich-to-Rich			
Correct	0.29 (0.20)	0.59 (0.30)	0.45 (0.22)
Lexical match	0.18 (0.18)	0.18 (0.16)	0.34 (0.22)
No lexical match	0.54 (0.34)	0.24 (0.31)	0.21 (0.26)
Schematic-to-Rich			
Correct	0.34 (0.28)	0.61 (0.34)	0.69 (0.27)
Lexical match	0.24 (0.25)	0.19 (0.20)	0.19 (0.23)
No lexical match	0.41 (0.35)	0.20 (0.30)	0.13 (0.21)
Rich-to-Schematic			
Correct	0.35 (0.25)	0.39 (0.29)	0.59 (0.36)
Lexical match	0.34 (0.23)	0.29 (0.25)	0.18 (0.23)
No lexical match	0.31 (0.25)	0.33 (0.24)	0.24 (0.26)
Total			
Correct	0.32 (0.26)	0.53 (0.30)	0.63 (0.31)
Lexical match	0.26 (0.24)	0.24 (0.22)	0.21 (0.23)
No lexical match	0.42 (0.30)	0.23 (0.27)	0.16 (0.23)

Table 15. Mean proportion of each response type out of the four relevant trials by age and condition

To evaluate whether children's error patterns changed with age and condition, their mean proportions of each error out of the four trials were entered into a 3 (Age) x 4 (Condition) x 2 (Error type) ANOVA. Age x Error type interaction was significant, F (6, 229) = 6.23, $p < .01$, $\eta_p^2 = .05$, suggesting that children's errors declined differently with age. A follow-up 3 (Age) x 2 (Condition) ANOVA was performed for each error type. For no lexical match errors, the effect of condition was not significant, F (3, 229) = 2.33, $p = .075$, $\eta_p^2 = .03$, but a main effect of age was significant, F (2, 229) = 20.69, $p < .001$, $\eta_p^2 = .15$, demonstrating that this type of error decreases with age during the preschool years. For lexically matching errors, however, the results were different. An Age x Condition interaction was significant, F (6, 229) = 2.95, $p < .01$, $\eta_p^2 = .07$. For Schematic-to-Schematic condition, there was no significant age difference albeit marginal, F (2, 58) = 2.87, $p = .065$, $\eta_p^2 = .09$. Similarly, for Schematic-to-Rich condition ($F < 1$) and for Rich-to-Schematic condition ($p = .09$), the main effect of age was not significant. However, for Rich-to-Rich condition, age effect was significant, F (2, 57) = 4.87, $p < .05$, $\eta_p^2 = .15$. Five-year-old children made *more* Lexical Match errors than 3- or 4-year-old children. In sum, while not lexically matching errors decreases with age across all conditions, the age-related decrease was not evident in lexically matching errors. Rather, oldest preschoolers made proportionately more errors than younger groups on the basis of their mother tongue's lexical categories when they viewed the spatial relations only with rich objects. (Because the current spatial analogies test did *not* present object match alternatives, children's errors could be classified on the basis of spatial relations only. See Appendix F for a complete list of the frequency and proportion of children choosing each alternative (including correct choices) for each spatial analogy item by age and condition.

Analyses of recoded data. Finally, we recoded children's responses to the *on* and *above* items so that both *on* and *above* alternatives were correct answers, in line with Korean lexical categories of spatial relations, to see if the results would change. The ANCOVA analyses of the recoded data yielded qualitatively similar patterns of results as the analyses of the original data. The difference was that, for cross-type generalization, a 2 (Condition: Schematic-to-Rich vs. Rich-to-Schematic) x 3 (Target relation) x 3 (Age) ANCOVA yielded a significant Target relation x Condition interaction in addition to the main effects for age and condition. The interaction arose because generalization of *above* relations did not differ across condition after recoding the data.

For within-type generalization, the ANCOVA yielded significant main effects for age, F (2, 99) = 4.24, $p < .05$, $\eta_p^2 = .08$, and condition, F (1, 99) = 13.72, $p < .001$, $\eta_p^2 = .12$, as well as a significant Age x Condition interaction, F (2, 99) = 5.59, $p < .01$, $\eta_p^2 = .10$. However, there was no significant effect of Target relation in this recoded data. Three-year-old children equally performed in Schematic-to-Schematic (M = 5.84, SD = 2.54) and Rich-to-Rich (M = 5.47, SD = 1.78) conditions, $F < 1$. Also, 4-year-old children tended to do better in Schematic-to-Schematic condition (M = 8.85, SD = 2.89) than Rich-to-Rich (M= 7.45, SD = 2.28) condition but the difference was not significant, F (1, 38) = 2.89, $p = .097$, $\eta_p^2 = .07$. In contrast, 5-year-old children showed a highly significant condition effect, F (1, 39) = 26.61, $p < .001$, $\eta_p^2 = .41$, showing almost perfect performance in the Schematic-to-Schematic condition (M = 11.05 out of 12, SD = 1.69) and much lower performance in the Rich-to-Rich condition (M = 7.40, SD = 2.74). The results regarding age effect also did not change. For Schematic-to-Schematic condition, univariate ANOVA revealed significant age effect, F (2, 57) = 23.29, $p < .001$, $\eta_p^2 = .45$. Posthoc Bonferroni tests demonstrated that 5-year olds (M = 11.05, SD = 1.69) performed significantly better than 4-year-olds (M = 8.85, SD = 2.89) who did significantly better than 3-year-olds (M = 5.84, SD = 2.54). For Rich-to-Rich condition, there was a significant age effect, F (2, 56) = 4.60, $p < .05$, η_p^2 = .14. Posthoc tests revealed five- (M = 7.40, SD = 2.74) and four-year olds (M = 7.45, SD = 2.28) did not differ from each other but each performed significantly better than 3-year-olds (M = 5.47, SD = 1.78).

Discussion

The results of the second study show developmental changes in the ability to generalize spatial relations between similar types of objects. Overall, three-year-olds performed at chance, indicating that they failed to transfer the spatial relations. Four- and five-year-old children, however, performed above chance, demonstrating that they successfully generalized the spatial relations. Furthermore, the results of ANCOVA tests reveal that the age-related improvement is more outstanding in generalization between schematic depictions than in generalization between rich depictions. Children's accurate mapping of spatial relations did not improve between 4 and 5 years of age in Rich-to-Rich generalization, whereas the accuracy continuously improved between 3- and 5-year-old children in Schematic-to-Schematic generalization.

The central question of this research was whether a schematic illustration of a spatial relation would promote children's generalization of the spatial relation better than a rich illustration. Study 2 results show that the answer is yes but only for the oldest preschoolers. Five-year-olds' performance was more accurate with geometric shapes, consistent with previous findings showing the advantage of perceptually simple objects in transfer of relations (e.g., Kaminski & Sloutsky, 2006; Kaminski, Sloutsky, & Heckler, 2008; Rattermann, Gentner, & DeLoache, 1990; Son, Smith, & Goldstone, 2011). This advantage was, however, not manifest in 3- and 4-year-old children. Specifically, 4-year-olds performed equally with geometric shapes and rich objects, regardless of the spatial relations. Also, 3-year-olds' performance was equal with geometric shapes and rich objects, with an exception that they performed worse when the sample was an *above* relation depicted with rich objects. Together, the advantage of schematic objects in transfer of spatial relations was clearly observed only in the oldest preschool children. Thus, it appears that, for within-type spatial analogies, the impact of object type varies across age (and spatial relation for the youngest preschoolers).

Study 2 results also reveal that the type of spatial relations significantly impacted generalization only in 3-year-old children who viewed rich objects. These children were significantly worse at generalizing *above* relations than the other relations. Although we did not make specific predictions about generalization of *above* relations compared to other relations, it is somewhat surprising because infant work indicates that infants could form the *above* category by 6 months, similar to the containment category. Surely, future research needs to replicate this finding. It raises the possibility that infants might fail to categorize *above* relations if tested with referents and figures both varying, and both real objects, which has not been tested yet in the infant spatial categorization literature. Norbury, Waxman, and Song (2011) suggested that less specific relations may be less likely to be noticed than specific relations. In this view, *above* relations where two objects are not in contact could be least specific among the tested relations. Thus, the relations are less likely to be processed; children might tend to process individual objects separately and try to find ways to connect concrete objects. However, at older ages of 4 and 5 years, children's generalization of the three spatial relations was equal, when the spatial vocabulary was controlled for. It is possibly because all three relations tested were relatively easy to children of these ages. Altogether, our hypothesis that containment relations would be more readily generalized than support relations was not supported by the results. Nonetheless, the youngest preschool children performed above chance only when the target relations were containment in the Rich-to-Rich condition, suggesting that containment relations are somewhat more readily recognized by the youngest children than other spatial relations, with this specific setting of transfer (i.e., Rich-to-Rich transfer). Thus, the results suggest that the spatial relation effect varies across age and type of objects.

In addition, the results of Study 2 again demonstrate that children's within-type spatial analogy skills significantly correlated with their acquisition of locative terms, but not their acquisition of shape vocabulary when the age of children was controlled for. This finding supports our hypothesis that generalization of spatial relations would be more strongly associated with children's acquisition of locative terms than their acquisition of shape names.

Why is there no condition effect in 3- and 4-year-old children in this second study? In this within-type transfer, children viewed one type of objects only, either geometric shapes or rich objects. One possibility is that it is more challenging for younger preschool children to perceive the spatial relation itself between two shapes when the relation was depicted only with abstract shapes. Perhaps they require a positive hint that helps encoding spatial relations. Indeed, during the experiment, several 3-year-old children labeled the scenes with names of concrete objects, such as ‘snowman’ (a circle on another circle), ‘car’ (a small square on a large rectangle), ‘donut’ (a small circle in a large circle) and ‘ring’ and so on. This voluntary labeling suggests that younger preschoolers perceived the scenes with two abstract shapes as one concrete object. In other words, younger children’s processing may focus on objects rather than spatial relations between two abstract elements. In contrast, the oldest preschool children of age 5 years seem readily able to pick up the spatial relation information from the depictions consisting of abstract geometric shapes, consequently demonstrating the advantage of schematic objects.

CHAPTER 4

GENERAL DISCUSSION

Sensitivity to the spatial arrangement between and among objects is evident early in development. Yet, despite its early inception, young children do not always generalize the spatial arrangement from one set of objects to another. Also, studies examining children's understanding of the model-room correspondence indicate that young children's appreciation of the correspondence is strongly influenced by object similarity. Together, these findings reveal that generalization of spatial arrangement continues to develop during preschool years.

In the present study, we aimed at further investigating young children's ability to generalize spatial arrangements, using a task of spatial analogies**.** Specifically, we sought to examine how the perceptual features of the objects depicting spatial relations impact young children's generalization of spatial relations. We also examined possible effects of targeted spatial relation, child age and spatial vocabulary on young children's ability to generalize spatial relations.

We began by testing young children's generalization of spatial relations (*on*, *in*, and *above*) with a spatial analogies test in which the relations were generalized across object type. We also created the generalization setting to be similar to those in the previous studies testing older learners, to determine whether the previously observed discrepant findings in the effect of object type on spatial generalization were due to the methodological differences rather than the differences in domain of relations tested. The results supported our prediction. That is, the advantage of schematic objects was consistently exhibited across the age groups tested in the cross-type spatial analogies. Three- to 5-year-old children generalized spatial relations better to a novel type of objects when they viewed schematic objects (e.g., a square above a triangle) as the sample (the generalization basis) than when they viewed rich objects (e.g., a bird above a tree) as the sample of a spatial relation. These results are the first to demonstrate that more schematic depictions promote children's generalization of spatial relations, without spatial relations confounded with size relations.

Our second question, given that schematic objects are more effective than rich objects in facilitating preschoolers' generalization of spatial relations between different types of objects, was whether schematic objects were more advantageous than rich ones in promoting generalization when spatial relations were transferred between the same types of objects, either between schematic objects or between rich objects. The results of Study 2 showed that in within-type spatial analogies test, only 5-year-old children, who were able to generalize spatial relations between rich objects, performed significantly higher with schematic objects than with rich objects. The benefit of schematic objects was not apparent in the age groups of 3- and 4-year-olds. Schematic objects failed to facilitate 3-year-old children's generalization of the spatial arrangement of objects, thus these children performed at chance with both types of objects, finding both conditions equally challenging. For 4-year-old children, who were able to generalize spatial relations between rich objects, schematic objects failed to further improve their generalization of the spatial arrangement of objects. These results are the first to show that the benefit of schematic objects is more consistent in cross-type transfer settings than within-type relational transfer settings.

Together, our results support the idea that generalization of spatial relations share important characteristics with generalization of other kinds of relations. Similar to how children and adults generalize other domains of relations such as monotonicity in relative size of objects (Kaminski & Sloutsky, 2010; Rattermann, Gentner, & DeLoache, 1990), symmetry and asymmetry relations (Son, Smith, & Goldstone, 2011), and mathematical relations (Kaminski & Sloutsky, 2009; Kaminski, Sloutsky, & Heckler, 2006, 2008), overall, a more schematic depiction of spatial relations is more effective in promoting children's generalization of spatial relations than a rich depiction.

What may be the mechanisms underlying the overall advantage of schematic depictions in generalization of spatial relations? And why, nonetheless, did younger preschool children fail to show a significant advantage of simple objects in within-type generalization? The overall advantage of schematic objects could be caused in two ways: (1) schematic objects could facilitate relational transfer, and (2) rich objects could hinder relational transfer. The symbolic reasoning view posits that schematic objects such as geometric shapes are more likely to be considered to refer to something else than rich, actual objects, which tend to emphasize the specific objects shown (Kaminski, Sloutsky, & Heckler 2008, 2010; Uttal et al., 2013). Possibly, this symbolic nature of schematic objects underlies facilitation of relational transfer. This mechanism also fits well with the less consistent advantageous of schematic objects in within-type generalization because a circle can represent concrete objects such as the sun, a ball, and an apple, while it rarely represents another geometric shape such as a triangle or a square.

Another possible mechanism is that a schematic depiction contains less features that are irrelevant to the relation, and consequently shortcuts the learner's abstraction process, reducing children's cognitive load to abstract a relation from the instance (Son et al., 2008, 2011). This mechanism appears to fit well with older children but may not fit equally well with the younger preschoolers, given that 3-year-old children in the Schematic-to-Schematic condition failed to see the spatial relation structure from schematic depictions only. Rather, they reacted to the abstract scenes as they were one object. Thus, for learners who have sparse knowledge of relations and rarely include the relational information in their representations, relational depictions that are too abstract may not help relational transfer.

Still another perspective is the information processing view. Rich objects contain more extraneous information than schematic objects, and the extraneous information possibly diverts children's attention away from the relational structure (DeLoache, 1987; Kaminski & Sloutsky, 2009; Rattermann, Gentner, & DeLoache, 1990; Uttal, Scudder, & DeLoache, 1997). Moreover, rich, actual objects may not only draw children's attention to the objects themselves, but also activate their known functions, which make it difficult for children to use the objects in a new way (e.g., seeing the objects as the components of a relation) (Petersen & McNeil, 2013). This mechanism relates more with how rich objects hinder relational transfer, and possibly explains the low performance of 5-year-old children who performed no better than 4-year-olds. Extraneous information of rich objects may create alternative ways to connect instances *relationally*, which also hinders children's use of the intended relations for mapping. Compared to schematic objects, rich objects convey more contextual information. For example, a drawing of a chicken may convey the properties of *alive, being able to move,* and *animal*, and a picture of an apple the concepts of *fruit* and *food*. Consequently, a picture of a chicken *left to* an apple can convey alternative relationships between the two constituent objects such as “a chicken is approaching the apple to eat,” or a “farm scene”, or a “food and animal who eats it”, or an “animate versus non-animate” relationships. Then, children must resolve competition among these alternative ways to connect instances in order to choose one response with rich objects, placing large cognitive demands. In contrast, with geometric shapes, which include less extraneous information, the selection demands may be minimal. This potential mechanism may be most relevant to the older preschoolers and adult learners, who likely have rich knowledge of objects and other relations. Indeed, a teacher at a childcare center where we tested children tried the Rich-to-Rich spatial analogies test and commented that one option image could be matched to the sample based on the commonality that they were “scenes in the living room.” The present study did not focus on testing between possible mechanisms nor did it collect children’s justification of their choices systematically. Follow-up studies should test these possibilities.

Despite the overall effectiveness of a schematic depiction of spatial relations, it is noteworthy that younger preschoolers fail to show a significant advantage of schematic objects in within-type generalization. Furthermore, when 3-year-old children performed above chance generalizing containment relations, it was only when they viewed rich options. Why is it so? First, the lack of the advantage of simplified objects appears to be also related to the fact that children viewed only one type of objects in a generalization task because we found the advantage of simplified objects in a cross-object-type spatial analogies test where children viewed both types of objects. Second, it is likely that 3-year-old children have difficulty abstracting (or immediately encoding) the spatial relation information without any additional cue that directs their attention to spatial relations, as suggested by their voluntary labeling of the scenes as objects. In the schematic-to-schematic condition where children viewed only geometric shapes with no additional cue, children's attention may have been more allotted to shapes themselves, and tried to find ways to match objects in the absence of the salient object match (e.g., a octagon and a circle). Third, recall that while 3-year-old children overall were not able to generalize the spatial relations, they were able to generalize containment relations when they were presented with rich objects typically functioning as *containers* in the choices. Kaminski, Sloutsky, and Heckler (2005, 2006) emphasized that the relevant concreteness might facilitate learning although they hinder transfer of the learning to novel isomorphic situations. According to the view, the typical containers such as basket and cup could facilitate at least 'recognition' of the containment relations in the choice, and the other choices could serve as comparisons. Perhaps, 4-year-old children are likely to transition from the inability to encode the spatial relation information without any additional cue (as 3-year-olds) to successfully noting spatial relations from pictures consisting of geometric shapes (as 5-year-olds).

The results of the present studies also supported another prediction that there would be considerable development in the ability to generalize spatial relations between the ages of 3 and 5 years. First, comparison to chance indicates age-related differences. Overall, 3-year-old children failed to generalize the spatial relations, whereas 4- and 5-year-old children were able to do so. It is unlikely that 3-year-olds' failure to generalize the spatial relations is due to their failure to understand the test or instruction given that they showed a tendency to match object shapes in pilot test using the same procedure and instructions. Furthermore, they provided evidence for generalizing containment relations (by performing above chance) in some conditions. Thus, they did understand the instruction of the test, and their overall chance performance indicates their limited ability to use spatial relations for generalization. In addition, 5-year-old children generalized the spatial relations in all conditions of transfer tested in the present research, whereas 4-year-old children failed to generalize the spatial relations from rich objects to schematic objects. Thus, it appears that the ability to generalize spatial relations continues to develop during the preschool years, and it becomes relatively stable by 5 years of age reaching an expert level with abstract representations of spatial relations. These results are analogous to previous findings indicating that young children have difficulty generalizing location information and the ability to process relative positions of three objects increases during the preschool years (Loewenstein & Gentner, 2005; Rattermann, Gentner, & DeLoache, 1990). Also, the results are consistent with the view that development is having increasingly abstract representation.

Moreover, the results of ANCOVAs provide further information about the developmental changes. Recall that the age effect was not qualified by other factors in cross-type transfer, whereas it was qualified by target relation and object type in within-type transfer. Specifically, on the items of *on* and *in*, children's performance did not differ across age in the Rich-to-Rich transfer, but 3- and 5-year-olds' performances significantly differed from each other in Schematic-to-Schematic transfer. Unlike those spatial relations, on the items of *above* relations, children performed similarly across age in the Schematic-to-Schematic transfer, and 4-year-olds' performance was significantly more accurate than 3-year-olds' performance in the Rich-to-Rich transfer. These results suggest that (1) the developmental changes occur more consistently in the ability to make far transfer (transfer between objects belonging to different types) than in the ability to make near transfer (transfer between the same types of objects); and that (2) in near transfer settings, developmental changes occur with schematic objects, but not with rich objects, at least for containment and support relations. What could have caused the different developmental patterns with *above* relations remains an open question.

Although in the current study 3-year-old children overall failed to generalize basic spatial relations among objects, it does not mean that 3-year-old are unable to generalize spatial relations in any generalization tasks. In fact, 3-year-old children were successful at relational matching on both the Generic and Concrete questions such as findings of Kaminski and Sloutsky (2010) and Loewenstein and Gentner (2005). The current spatial analogies task provided four pairs of objects composed of 8 different objects during one item, and provided 12 different items (a bowl and a spoon -> a dog and a doghouse, glasses on a book, and so forth). Possibly, diversity of the stimuli increased the cognitive load. In other studies, however, young children were presented with two sets of objects that were less diverse: three triangles to three dogs in Kaminski and Sloutsky (2010) and three gray cards to three blue cards in Loewenstein and Gentner (2005).

We had posited that how readily young children generalize a spatial relation might vary across spatial relation, with children possibly generalizing containment relations more easily than those of support. However, our results do not support this hypothesis. We found no evidence that particular spatial relations are more readily generalized than others among the three relations tested. Rather, preschool children generalized *above*, *on*, and *in* relations at approximately equal ease across the two studies, except for the 3-year-old children who viewed rich objects as both the sample and the choices. These 3-year-olds performed significantly worse on the *above* items than on the items of containment and support. This finding needs to be replicated in further studies. Again, however, there was no significant advantage of containment relations over support relations.

Although comparison among spatial relations does not indicate any relative ease of containment generalization over generalization of support, it is noteworthy that comparison to chance revealed that 3-year-old children, who overall failed to generalize spatial relations showed evidence of generalization of containment relations in the Rich-to-Rich transfer (Study 2) and the Schematic-to-Rich transfer (Study 1). That is, the youngest preschool children matched containment relations when the relations were depicted with perceptually rich, known objects in both the sample and choices, and when the relations were depicted with perceptually sparse shapes in the sample and with rich objects in the choices. One intriguing possibility is that their performance benefitted from the fact that rich depictions of containment relations presented objects typically functioning as “containers” such as a doghouse, basket, bottle, and fishbowl in the present study. Note that typical functions of a book or a house are not to support another object. Thus, if young children’s knowledge of the functions of objects is activated during the test, containment relations, but not support or *above* relations, are more likely to be noticed by the youngest preschool children. Similar to this possibility, Kaminski, Sloutsky, and Heckler (2005, 2006) argued that relevant concreteness may help communicate the to-be-learned concept. However, these researchers argued the relevant concreteness cannot have advantage for *transfer*. Interestingly, our data also indicate that

3-year-olds fail to generalize containment relations when the sample consisted of rich objects. Their success was observed only when the options were rich objects.

The lack of a significant advantage of containment relations over support in the present study is inconsistent with previous findings from infants. Given that all of the three spatial relations tested are among the earliest acquired spatial terms and that young children are biased for processing support relations (Plumert, Ewert, & Spear, 1995) as well as containment (Plumert & Hawkins, 2001) compared to proximity relations (*next to*), it may be that the differences among *on*, *in*, and *above* relations that are evident earlier in development are narrowed by the preschool years. However, it is an open possibility that these spatial relations are more easily generalized than spatial relations that are acquired relatively later, such as *between, middle,* next to, and *left-right* relations.

Finally, the present results aimed to capture the link between children's performance on the spatial analogies test and their acquisition of spatial vocabulary, particularly shape names and locative terms. First, our data demonstrate that comprehension and production of both shape names and locative terms significantly increase during the preschool years, consistent with previous findings that children acquire considerable shape names and locative terms in early childhood (e.g., Clements, 1998; Oberdorf & Taylor-Cox, 1999). The results from detailed age comparisons demonstrated slight differences across the two studies. For example, in Study 1, children's productive vocabulary significantly increased at each age, while their comprehensive vocabulary significantly differed only between the ages of 3 and 4 years, not between 4 and 5 years. However, this pattern of results was not found in Study 2, demonstrating that production of shape names did not differ between the ages of 4 and 5 years. This difference might be due to sampling error.

More importantly, the present experiments reveal a more intimate link between particular spatial words and spatial analogy skills, a link between young children's acquisition of locative terms and their spatial analogy skills. In both within- and cross-object-type transfer of spatial relations, children's performance on the spatial analogies test significantly correlated with their locative terms only (comprehension in within-object-type transfer, production in cross-object-type transfer), not with shape names, when child age was controlled for. While this finding adds to the previous findings showing that mastery of spatial terms that are closely relevant to the given spatial reasoning skills predicts children and adults' particular spatial reasoning skills (Hermer-Vazquez, Moffet, & Munkholm, 2001; Pyers et al., 2010; Simms & Gentner, 2008), it seems contrary to the previous finding that broader range of spatial terms that excluded locative terms did predict children's performances on diverse spatial tasks including a spatial analogies task (Pruden, Levine, & Huttenlocher, 2011). However, the spatial relations used by Pruden et al. (2011) did not correspond to a single locative term (e.g., *on, in*), but were composed of multiple spatial concepts such as objects' shape identity, size, orientation in addition to their spatial relation or location. For example, children were asked to generalize a relation that two identical shapes differing in size were arranged on a vertical plane, a relation that two objects are orienting toward the right side, or a relation that two identical shapes are symmetrically arranged and partly overlapped. Hence, in order to choose the correct spatial arrangement match in their task, children were required to consider broader aspects of spatial concepts including shapes.

Then broader spatial terms including shape names and dimension words are arguably closely relevant to solving their spatial analogies test. In contrast, in the present spatial analogies test, all of the presented spatial relations corresponded to spatial prepositions, and choosing the correct answer in fact required children to ignore object shape. Perhaps these differences account for the discrepant findings in specificity of the link between spatial vocabulary and spatial analogies skills.

Unfortunately, the close association between these two measures (locative terms and spatial analogy skill) does not throw much light on the controversy over the mechanisms underlying the specific link between the acquisition of locative terms and performance on spatial analogies test. It is certainly possible that a third variable such as parental input emphasizing spatial thinking impacts both children's acquisition of locative terms and their spatial analogy skill. It may be also that individual children's ability to reason about spatial relations influences their mastery of locative terms. Despite these possibilities, it is also probable that children's acquisition of spatial labels enables children to better reason about the spatial relations. A natural experiment with adult Nicaraguan signers (that controlled for the effect of culture and cognitive maturity) has provided strong evidence that learning and using particular spatial labels promotes thinking about the particular spatial aspects (Pyers et al., 2010). Possibly, acquisition of certain spatial terms involves experience of hearing and producing a common spatial label applied to diverse situations (Gentner & Christie, 2010), which in turn may make children's representation of spatial relations more abstract, and these more abstract representation may be better retained in memory and better accessed for use (Christie & Gentner, 2014; Gentner, 2010; Gentner, Anggoro, & Klibanoff, 2011). Thus, acquisition of locative terms such as *on*, *in*, and *above* may facilitate children's retrieval and use of spatial relations when they solve the spatial analogies test. Although we cannot infer the direction of the relationship from the current correlational findings, regardless of the direction of the relationship, our results demonstrate that children's locative terms and their use of spatial relations for generalization vary hand in hand, even when age is controlled for. An important future direction will be to test the direction of the influence. One way to do so will be to train young children with novel locative terms for novel spatial relations, with shape names for novel shapes, and with non-spatial language, and then compare their spatial analogy skill.

Among several limitations of the current investigation, one was that the measure of children's comprehension of shape names included only a small number of shapes that were limited to relatively difficult shapes. The limited number of items might have resulted in relatively small variance in children's vocabulary score in comprehension of shape names. Thus, future research should attempt to replicate the relationship between spatial analogies and spatial vocabularies using more comprehensive measures of shape names and locative terms. Another limitation is that while this research suggests that previous discrepancy in findings is due to methodological differences, it does not tell exactly which aspect of the method is likely the main cause of the discrepancy. In this sense, the present research is a starting point. The next step will be to manipulate the potential methodological variables systematically and identify the factors that importantly interact with the impact of object type on relational generalization.

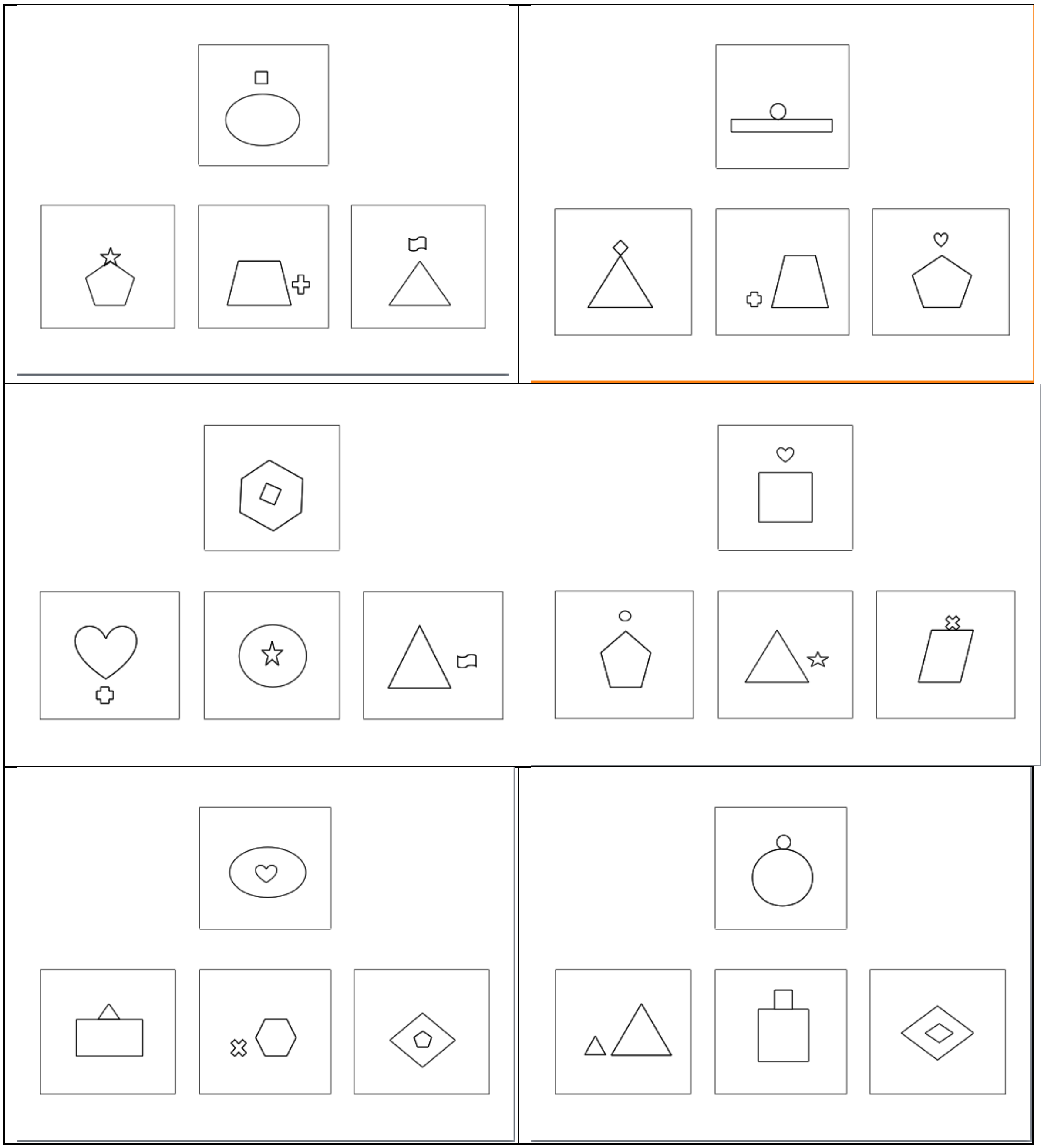
Furthermore, some results of the present research may be specific to Korean preschool children. Research has shown that infants' sensitivity to the distinction between spatial relations changes as children use the relevant spatial terms and increase their vocabulary level. For example, Choi (2009) found that Korean infants continue to be sensitive to the distinction between tight-fit and loose-fit relations whereas English-learning infants weaken their sensitivity to the same distinction by 29 months of age. Similar cross-linguistic differences may exist in children's use of relations for generalization. Specifically, unlike English-speakers, Korean speakers are not required to distinguish between *on* and *above* relations. Moreover, Korean speakers commonly describe situations that English-speakers would differentiate with *on* and *in* using a more inclusive locative term, -*eh*. For instance, 'an egg in a basket' and 'a doll on a blanket' can be described as "an egg is at a basket" and "a doll is at a blanket" in Korean. Thus, the current spatial analogies task that asked children to differentiate and generalize *on*, *in*, and *above* relations might have been difficult for Korean-speaking children. English requires its speakers to consistently distinguish among the three relations. Therefore, it is possible that English-speaking children may produce higher performance on this test and higher correlation between locative term acquisition and their performance on the spatial analogies test.

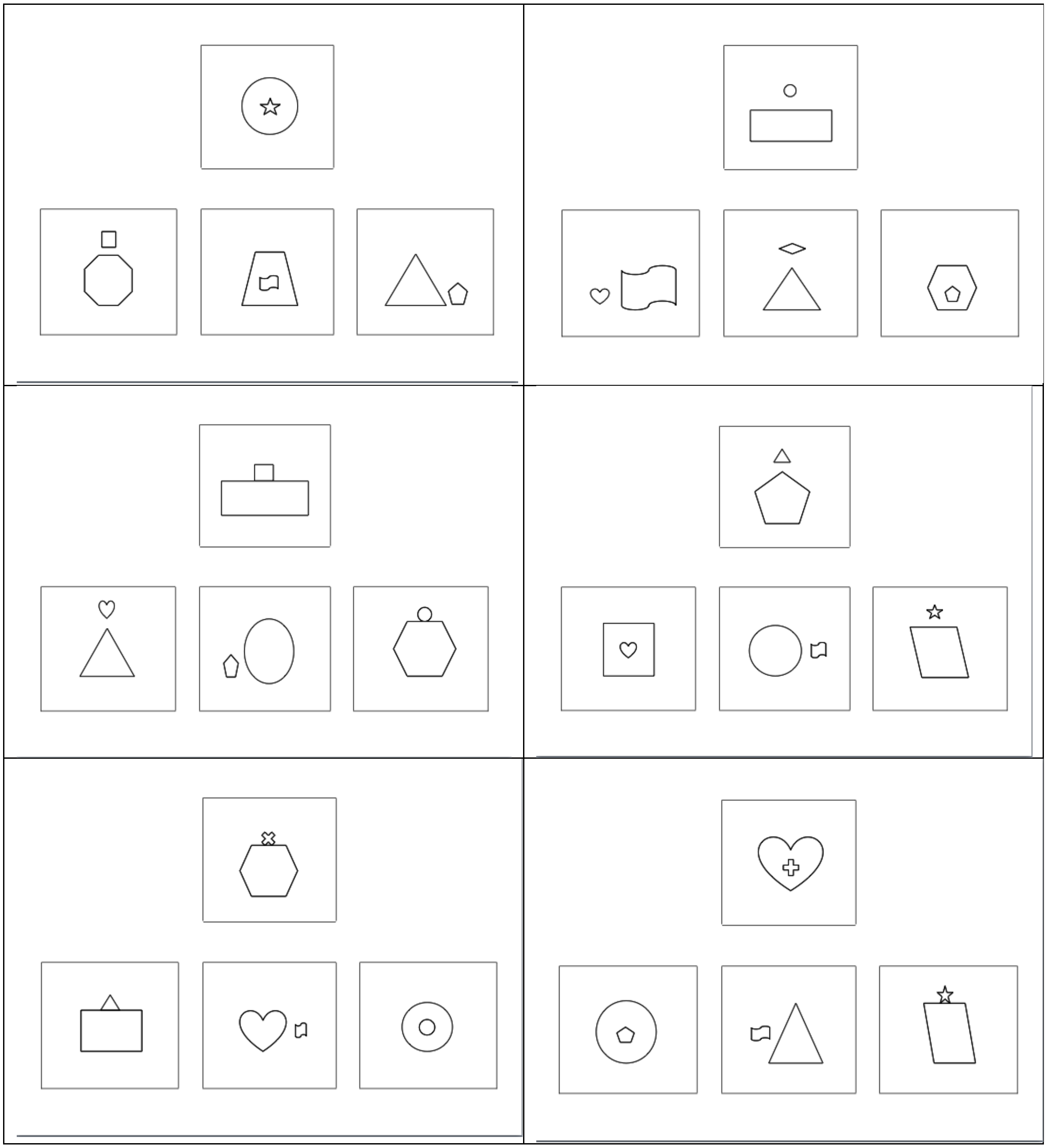
In conclusion, the present research extends the beneficial effect of object simplicity in relational transfer to the domain of spatial relations, and demonstrates that perceptually simple depictions better facilitate preschool-children's generalization of spatial relations than do rich depictions involving familiar objects. The present research further indicates that this advantage of object simplicity is more consistent across age for generalization between different types of objects than that between same types of objects. In addition, the current research shows that generalizing relations of *on*, *above*, and *in* from one instantiation to another is not always easy for preschool-aged children, but improves during the preschool years. Finally, young children's acquisition of locative terms is more intimately linked to their spatial analogy skills than is their acquisition of shape names, suggesting specificity of the link between spatial language and spatial skills. These findings have implications for preschool education. Using schematic depictions of abstract concepts can help children transfer relational concepts in general. However, adults should consider that demonstrating relations using only abstract shapes may not be helpful for very young children who cannot recognize the relational concept from the abstract instantiations. Also, theoretically, researchers might need to develop a theory that considers learners' developmental characteristics and the generalization settings.

Appendix A

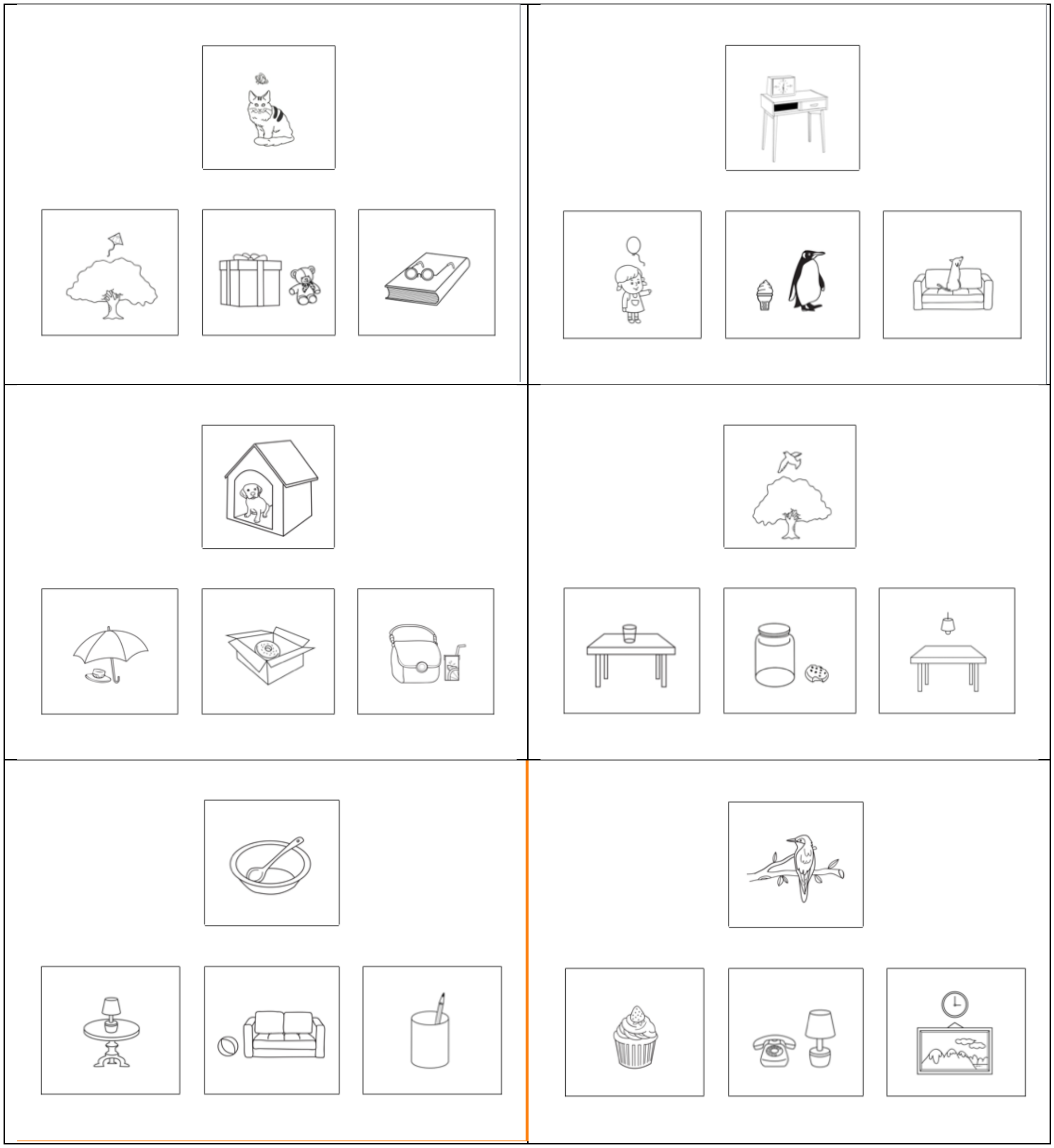
Spatial Analogies Test

(a) Spatial analogy items in Schematic-to-Schematic transfer condition

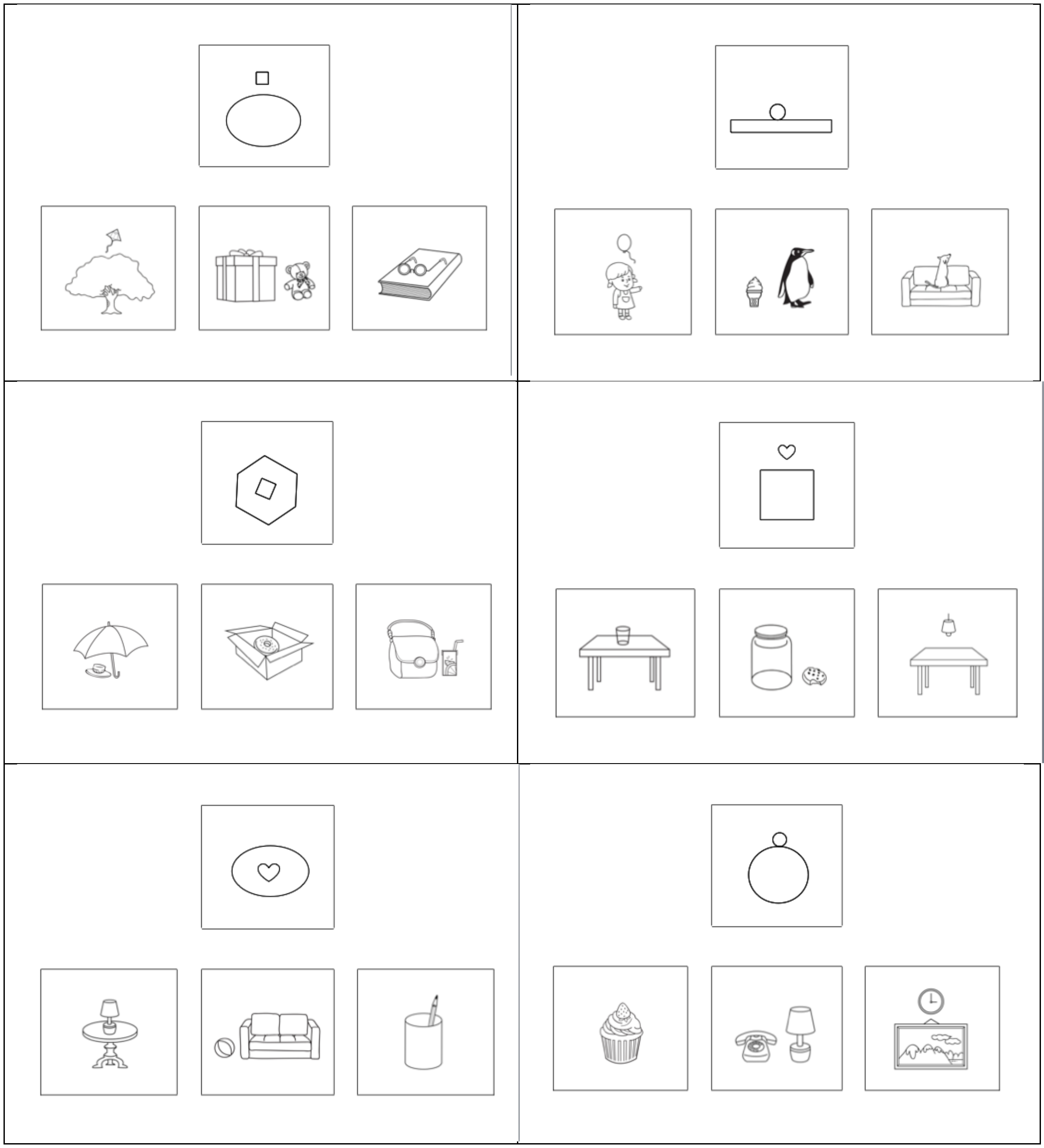


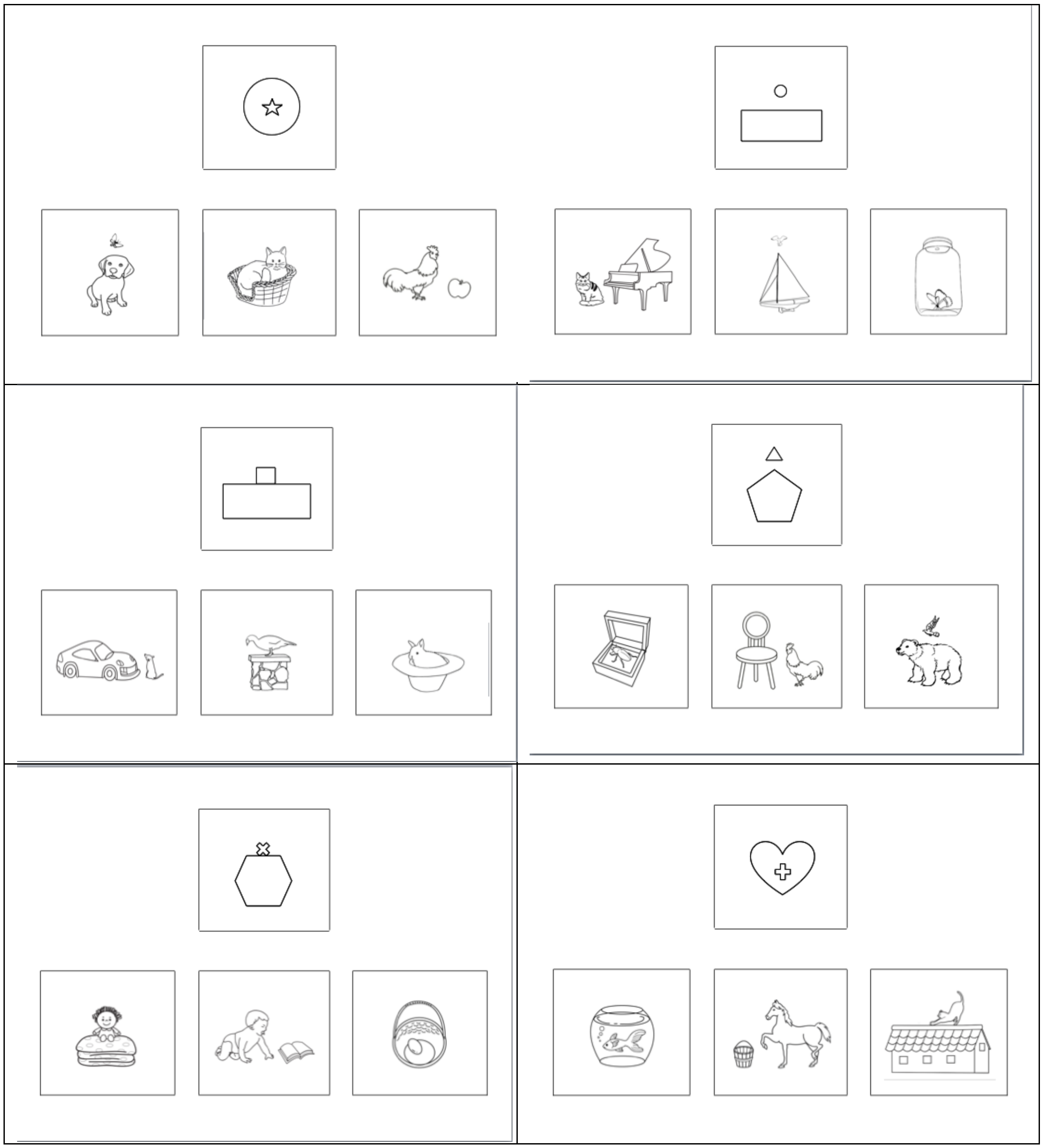


(b) Spatial analogy items in Rich-to-Rich transfer condition

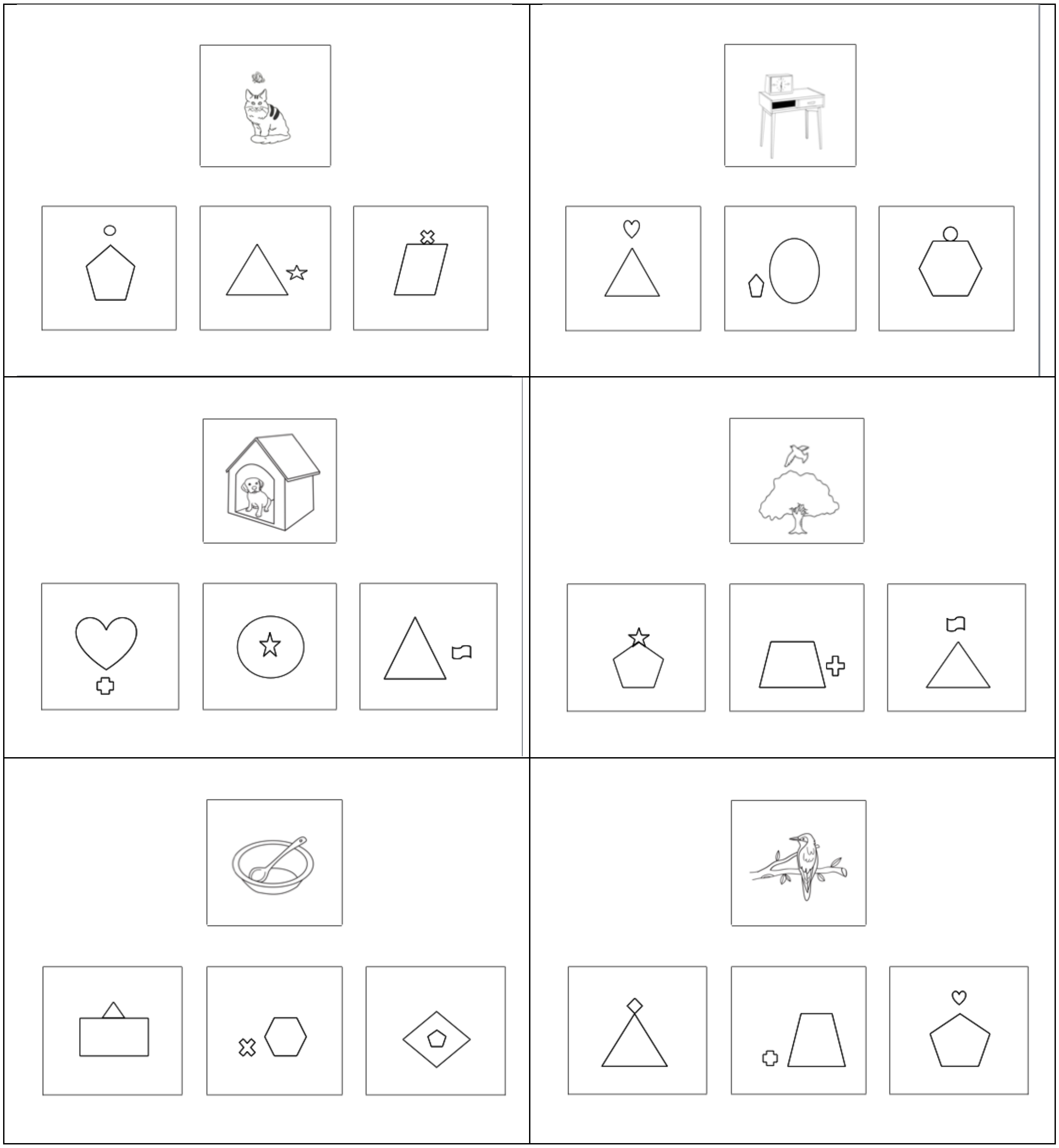


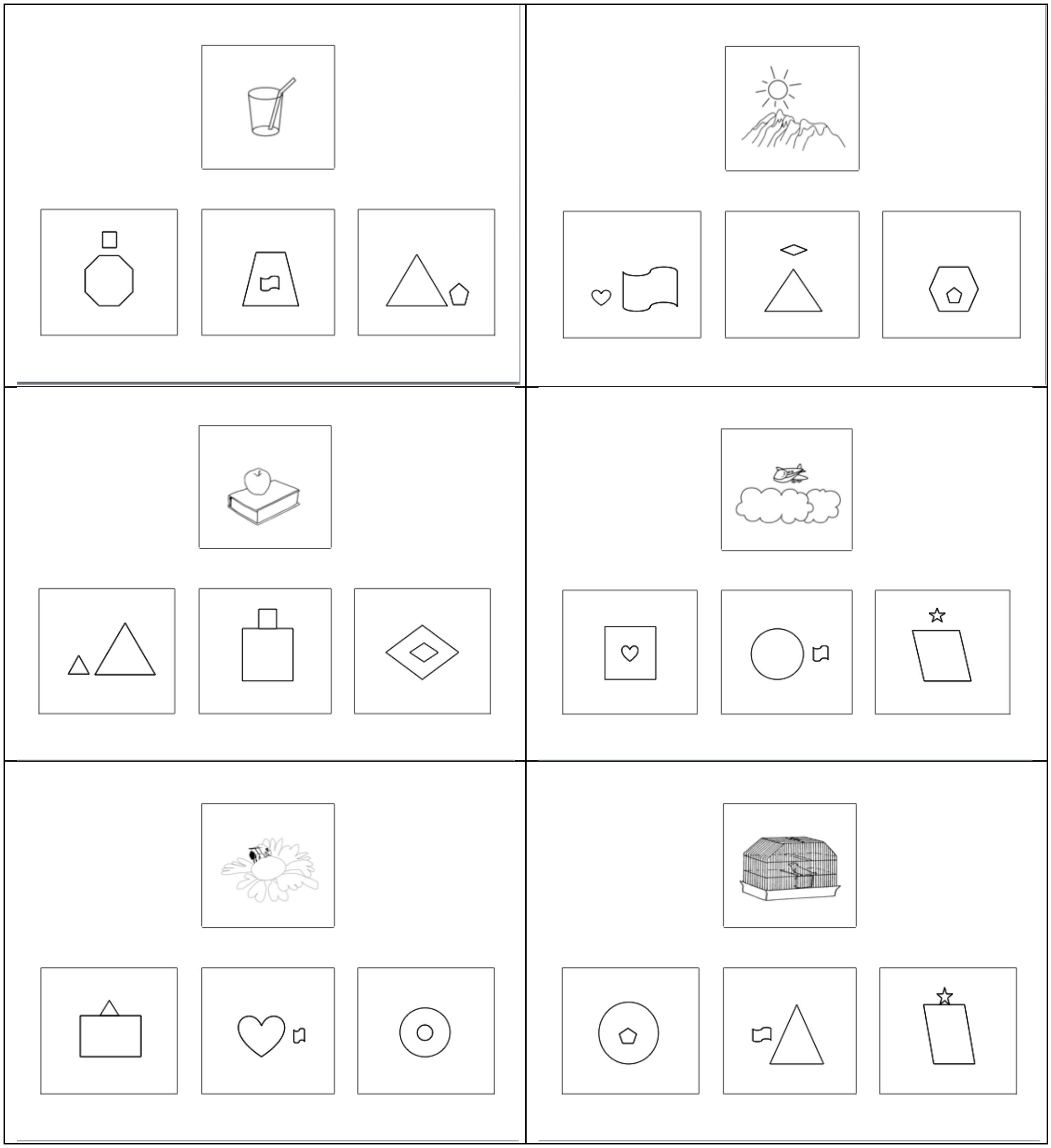
(c) Spatial analogy items in Schematic-to-Rich transfer condition





(d) Spatial analogy items in Richer-to-Schematic transfer condition





Appendix B

Test sheet of spatial analogies test with Korean instructions

Spatial Analogies Game

Date:

Condition
1The number of exemplars shown: 1 1The number of choices: 3 1Test order: □1 □2 □3 Target: □ shapes & symbols □ black/white line drawings Choices: □shapes & symbols □black/white line drawings

Subject information	
Subject ID: Child's Name: DOB:	Day care (Name): Sex: Age:

Korean instructions: 이제 선생님이랑 00 이랑, 그림카드의 짝꿍을 찾아주는 게임을 할 거에요. 먼저, 선생님이 00 이에게 그림을 하나 보여줄 거에요. 그리고나서 그림을 세 개 더 보여줄거에요. 그럼, 00 이가 그림들을 잘 보고, 셋 중에 어떤 그림이 먼저 보여준 그림이랑 가장 잘 맞는 짝꿍인지 말해주면 돼요. 알겠지요? 준비됐어요?

[연습과제] 먼저, 00 이가 이 게임을 어떻게 하는 건지 알 수 있도록, 선생님이랑 연습을 한 번 해 봐요. 자, 이 그림을 보세요 (pointing to the target picture, and waiting 3 sec before presenting the choice pictures). 이제 이 그림들을 보세요 (pointing to the three choice pictures, and waiting 3 sec). 자, 이 세 개의 그림카드 중에서 (continuous point to the three options) 어느 것이 여기 (pointing to the sample) 있는 그림이랑 가장 잘 맞는 짝일까요?

[본과제] 이 그림을 보세요 (pointing to the target picture, and waiting 3 sec before presenting the choice pictures). 그리고나서 이 그림들을 보세요 (pointing to the three choice pictures, and waiting 3 sec). 자, 이 세 개의 그림카드 중에서 (continuous point to the three options) 어느 그림 카드가 여기 (pointing to the sample) 있는 그림카랑 가장 잘 맞는 짝꿍일까요?

아동이 답하지 않을 경우, 한 번 더 질문한다. 이 중에서(세 개의 그림카드의 아래쪽을 순서대로 쭈욱 손으로 훑으면서) 어떤 게 이거랑(위의 표적 자극을 손으로 가리키면서) 가장 비슷해요?

Trial #	Child's choice	Notes	Correct?
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
Number of spatial relation		Number correct ON: Number correct IN: Number correct ABOVE:	Total score:

Appendix C

Spatial Language Test Script (Original English version)

Shape Names (Production). Now, you will see various shapes here. But I seem to have forgotten all my shape names, do you think you could help me name these shapes? If you don't know the name of the shape, it's okay! Just say "I don't know" and we'll move on to the next one.

Heart	diamond	parallelogram	trapezoid
Star	rectangle	square	circle
Octagon	oval	hexagon	triangle
pentagon			

Shape Names (Comprehension). So now I'm going to see if you can point to the shape I'm asking for. Can you find the_____?

diamond? semi-circle? hexagon? diagonal? pentagon?

Locative Terms (Production)--these are possible answers but they are not limited to only these. Do you think you could tell me with words where the bear is in relation to the cup? (If they say, "right here or right there!" Say: What if I cover my eyes? I can't see where the bear is anymore. Can you tell me with words where the bear is? If they keep saying, "right here", then start priming them with "is it in front of or to the right of the cup, etc.?") Once they produce a preposition word or if they keep saying "right here", then move on to the next spatial relation picture.

behind, in back of it, next to
under
in, inside
under, below
in front of, next to
far away from
(generally ask where the cup is) in the middle, in between
above, on top

Locative Terms (Comprehension). Can you point to the picture that matches the closest to what I ask for? In which picture is the...

bowl upside-down? (2 pictures)
bear below the bowl?
bear far away from the bowl?
bear under the bowl?
bear behind the bowl?
bear upside-down?
bear diagonal?
bear to the left of the bowl? (2 pictures)

Appendix D

Test sheet of Spatial Language Test with Korean instructions

<모양 단어 산출 과제> 이제, 여기에 여러 가지 모양들이 나올 거에요. 그런데 선생님이 이 모양들의 이름을 잊어버렸어요. 혹시 00 이가 아는 모양이 나오면 선생님한테 가르쳐 주세요. 만약 모르면 "모르겠어요" 하고 말해도 돼요. 그럼 다음 문제로 넘어갈 거에요. 알았죠? 자, 이건 무슨 모양일까?

1.	2.	3.	4.
5.	6.	7.	8.
9.	10.	11.	12.
13.			

<모양 단어 이해 과제> 자, 이번엔 선생님이 말하는 모양이 이 중에서 어떤 건지 찾아보세요.

1.다이아몬드/마름모 2. 반원 3. 육각형 4. 대각선 5. 오각형

<공간 전치사 산출 과제> 이번엔 그림을 보고 곰이 어디에 있는지 말해 주세요. 자, 곰이 어디에 있죠? (만약 아동이 "여기요"라고만 응답할 경우에는) 자, 선생님이 이렇게 눈을 가리면 어때요? 선생님은 곰이 어디 있는지 안 보여요. 00 이가 선생님한테 곰이 어디 있나 말로 설명해 줄래요? → (또 여기 있다고 응답할 경우에는) 곰이 컵 앞에 있나요? 아니면 오른쪽에 있나? → (여전히 여기 있다고 하면 통과) 그래요. 자, 이번엔 곰이 어디에 있나요?

1.	2.	3.
4.	5.	6.
7.	8.	

<공간 전치사 산출 과제> 이번엔 그림을 보고 곰이 어디에 있는지 말해 주세요. 자, 곰이 어디에 있죠? (만약 아동이 "여기요"라고만 응답할 경우에는) 자, 선생님이 이렇게 눈을 가리면 어때요? 선생님은 곰이 어디 있는지 안 보여요. 00 이가 선생님한테 곰이 어디 있나 말로 설명해 줄래요? → (또 여기 있다고 응답할 경우에는) 곰이 컵 앞에 있나요? 아니면 오른쪽에 있나? → (여전히 여기 있다고 하면 통과) 그래요. 자, 이번엔 곰이 어디에 있나요?

1.	2.	3.
4.	5.	6.
7.	8.	

<공간 전치사 이해> 이제, 마지막으로, 선생님이 말하는 그림이 어디에 있는지 00 이가 찾아주세요.

1.이 두 그림 중에서 어떤 게 컵이 거꾸로 있는 그림이지?

2. 어느 그림이 곰이 컵 아래에 있는 그림지?

3. 곰이 컵에서 멀리 떨어져 있는 것은 어느 거에요?

4. 곰이 컵 아래에 있는 것은?

5. 곰이 컵 뒤에 있는 것은?

6. 곰이 거꾸로 있는 것은 어떤 거에요?

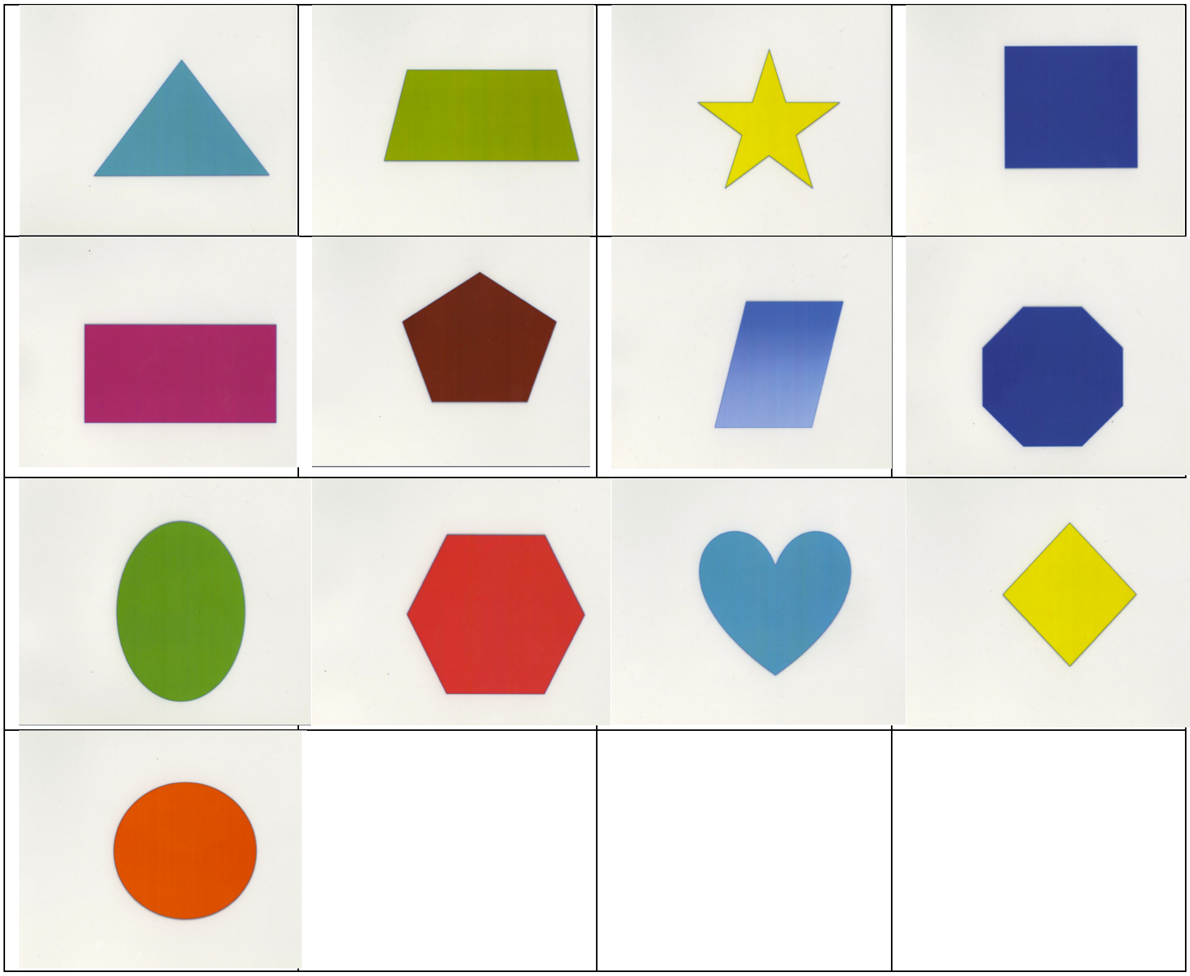
7. 곰이 대각선으로 있는 것은 어느 그림일까요?

8. 곰이 컵의 왼쪽에 있는 그림은 어느 것일까요?

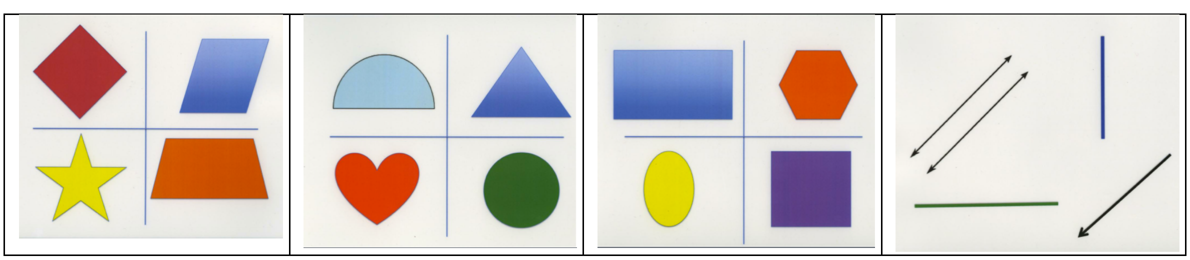
Appendix E

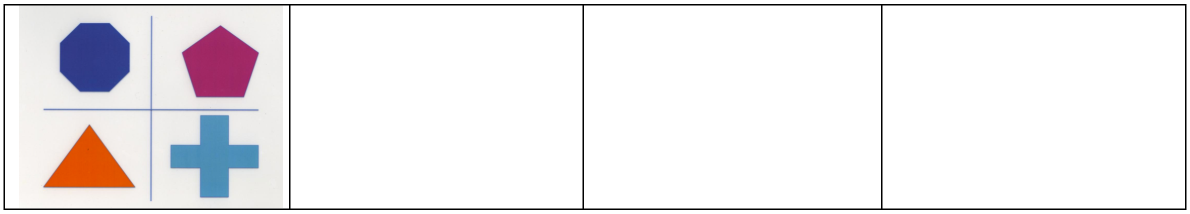
Spatial Language Test

(a) Shape Names (Production). The following order was used for use Korean children

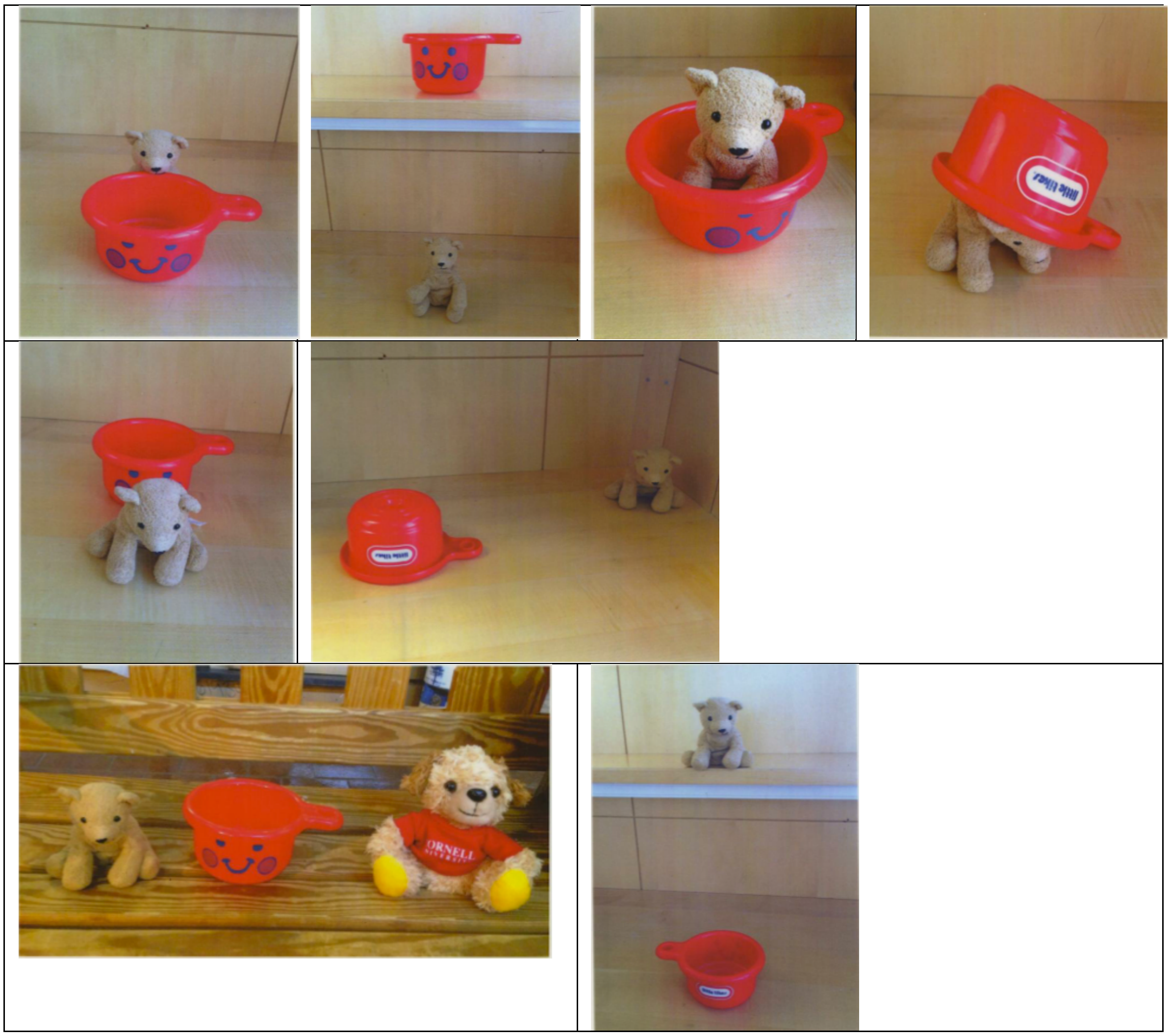


(b) Shape Names (Comprehension).





(c) Spatial Relations (Production)

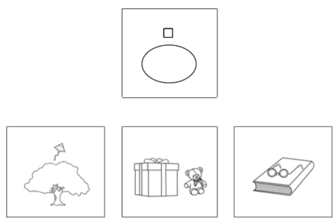
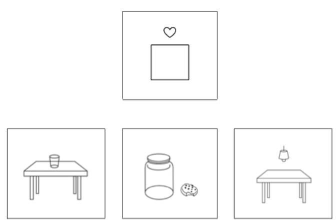
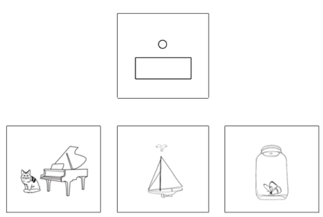
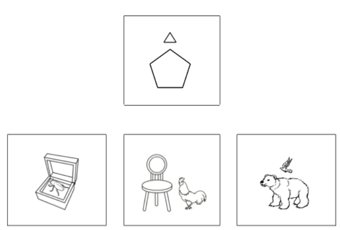


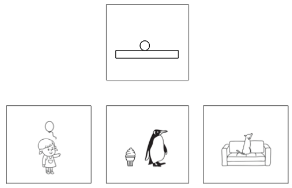
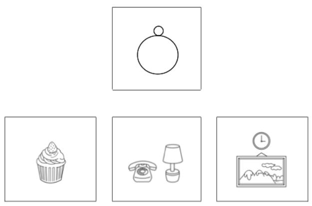
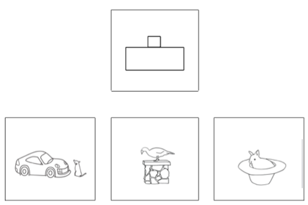
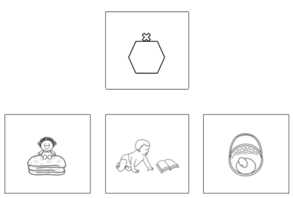
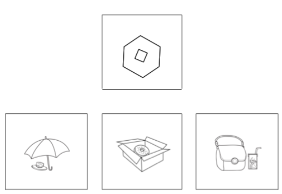
(d) Spatial Relations (Comprehension).

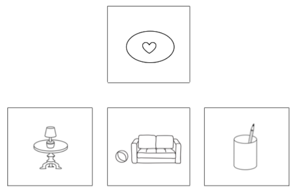
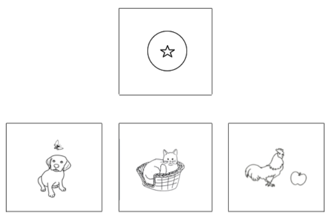
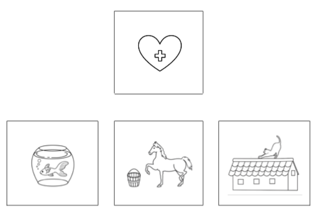
Appendix F

Distribution of Children's Choices on the Spatial Analogies Test

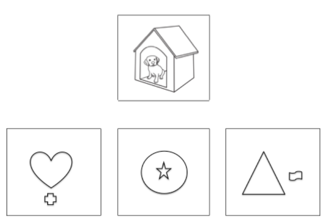
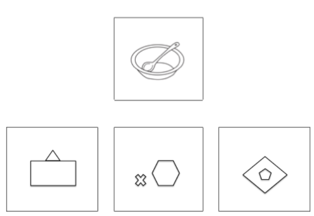
(a) Schematic-to-Rich condition (Frequency and proportion)

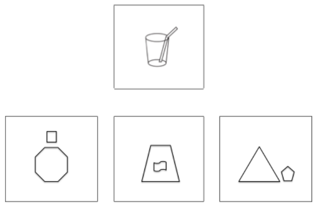
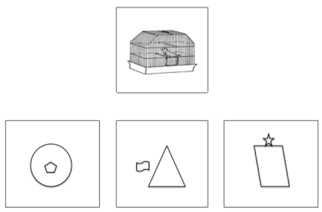
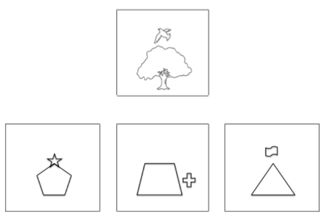
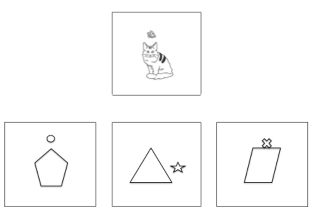
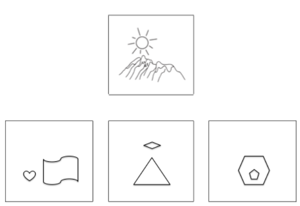
Spatial Analogy Item	Age	Option		
		1	2	3
	3	6 (30%)	9 (45%)	5 (25%)
	4	12 (60%)	6 (30%)	2 (10%)
	5	13 (65%)	5 (25%)	2 (10%)
		1	2	3
	3	7 (35%)	6 (30%)	6 (30%)
	4	1 (5%)	5 (25%)	14 (70%)
	5	3 (15%)	1 (5%)	16 (80%)
		1	2	3
	3	7 (35%)	8 (40%)	4 (20%)
	4	3 (15%)	9 (45%)	8 (40%)
	5	2 (10%)	14 (70%)	4 (20%)
		1	2	3
	3	8 (40%)	10 (50%)	1 (5%)
	4	7 (35%)	7 (35%)	6 (30%)
	5	5 (25%)	2 (10%)	13 (65%)

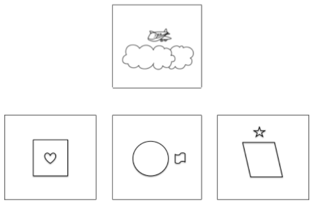
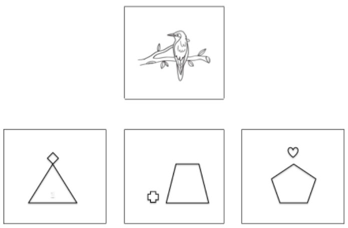
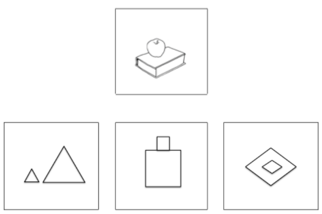
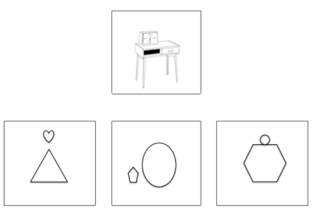
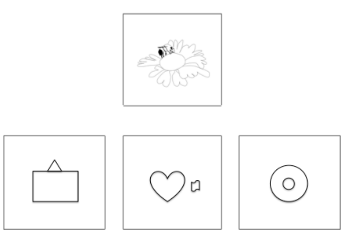
		1	2	3
	3	3 (15%)	10 (50%)	7 (35%)
	4	5 (25%)	4 (20%)	11 (55%)
	5	3 (15%)	2 (10%)	15 (75%)
		1	2	3
	3	8 (40%)	7 (35%)	5 (25%)
	4	12 (60%)	1 (5%)	7 (35%)
	5	11 (55%)	2 (10%)	7 (35%)
		1	2	3
	3	10 (50%)	6 (30%)	4 (20%)
	4	5 (25%)	14 (70%)	1 (5%)
	5	2 (10%)	16 (80%)	2 (10%)
		1	2	3
	3	7 (35%)	5 (25%)	7 (35%)
	4	7 (35%)	8 (40%)	5 (25%)
	5	14 (70%)	2 (10%)	4 (20%)
		1	2	3
	3	9 (45%)	10 (50%)	1 (5%)
	4	3 (15%)	12 (60%)	4 (20%)
	5	3 (15%)	14 (70%)	3 (15%)

		1	2	3
	3	6 (30%)	6 (30%)	7 (35%)
	4	4 (20%)	8 (40%)	8 (40%)
	5	12 (60%)	2 (10%)	6 (30%)
		1	2	3
	3	4 (20%)	11 (55%)	4 (20%)
	4	5 (25%)	13 (65%)	2 (10%)
	5	1 (5%)	19 (95%)	0 (0%)
		1	2	3
	3	9 (45%)	5 (25%)	5 (25%)
	4	8 (40%)	8 (40%)	4 (20%)
	5	16 (80%)	2 (10%)	2 (10%)

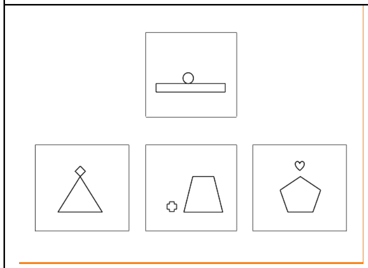
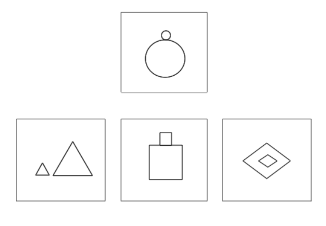
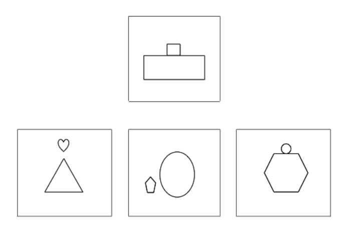
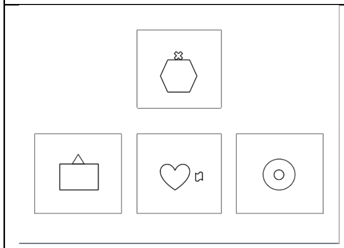
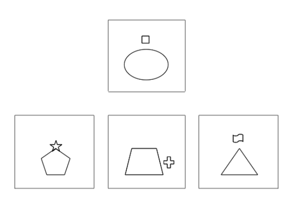
(b) Rich-to-Schematic condition

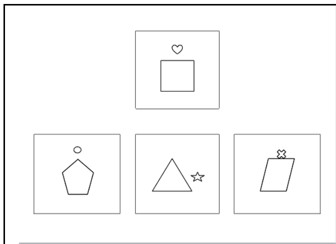
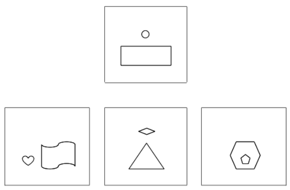
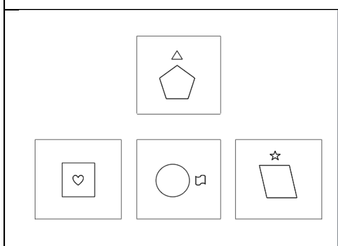
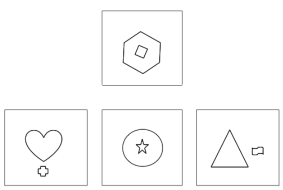
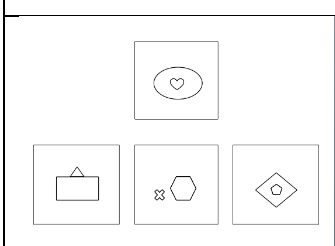
Spatial Analogy Item	Age	Option		
		1	2	3
	3	4 (20%)	7 (35%)	9 (45%)
	4	4 (20%)	4 (20%)	12 (60%)
	5	4 (20%)	9 (45%)	7(35%)
		1	2	3
	3	5 (25%)	12 (60%)	3 (15%)
	4	3 (15%)	10 (50%)	7 (35%)

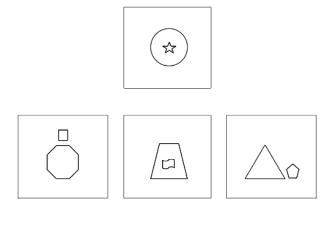
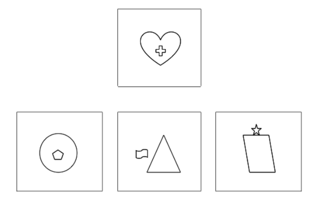
	5	4 (20%)	10 (50%)	6 (30%)
		1	2	3
	3	6 (30%)	8 (40%)	6 (30%)
	4	5 (25%)	13 (65%)	2 (10%)
	5	8 (40%)	10 (50%)	2 (10%)
		1	2	3
	3	4 (20%)	5 (25%)	11 (55%)
	4	6 (30%)	3 (15%)	11 (55%)
	5	12 (60%)	0 (0%)	8 (40%)
		1	2	3
	3	6 (30%)	8 (40%)	6 (30%)
	4	6 (30%)	9 (45%)	5 (25%)
	5	3 (15%)	7 (35%)	10 (50%)
		1	2	3
	3	7 (36.8%)	6 (31.6%)	6 (31.6%)
	4	7 (35%)	6 (30%)	7 (35%)
	5	10 (50%)	3 (15%)	7 (35%)
		1	2	3
	3	7 (35%)	4 (20%)	9 (45%)
	4	5 (25%)	10 (50%)	5 (25%)
	5	1 (5%)	16 (80%)	3 (15%)

		1	2	3
	3	5 (26.3%)	9 (47.4%)	5 (26.3%)
	4	4 (20%)	7 (35%)	9 (45%)
	5	0 (0%)	7 (35%)	13 (65%)
		1	2	3
	3	10 (50%)	5 (25%)	5 (25%)
	4	11 (55%)	3 (15%)	6 (30%)
	5	12 (60%)	5 (25%)	3 (15%)
		1	2	3
	3	5 (25%)	8 (40%)	7 (35%)
	4	3 (15%)	8 (40%)	9 (45%)
	5	0 (0%)	15 (75%)	5 (25%)
		1	2	3
	3	10 (50%)	5 (25%)	5 (25%)
	4	4 (20%)	8 (40%)	8 (40%)
	5	1 (5%)	4 (20%)	15 (75%)
		1	2	3
	3	2 (10%)	7 (35%)	10 (50%)
	4	7 (35%)	5 (25%)	8 (40%)
	5	9 (45%)	4 (20%)	7 (35%)

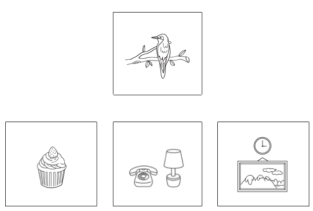
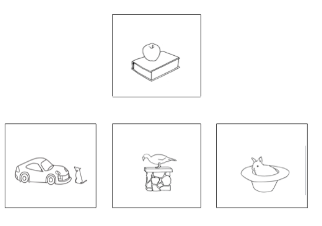
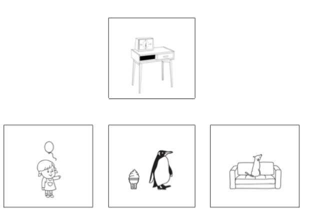
(c) Schematic-to-Schematic condition

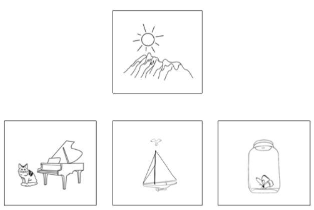
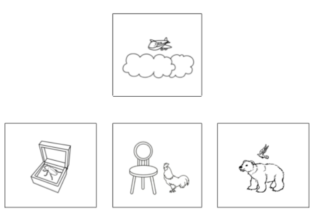
Spatial Analogy Item	Age	Option		
		1	2	3
	3	6 (30%)	7 (35%)	7 (35%)
	4	11 (55%)	3 (15%)	6 (30%)
	5	14 (66.7%)	4 (19%)	3 (14.3%)
		1	2	3
	3	3 (15%)	12 (60%)	5 (25%)
	4	2 (10%)	16 (80%)	2 (10%)
	5	0 (0%)	21 (100%)	0 (0%)
		1	2	3
	3	1 (5%)	7 (35%)	12 (60%)
	4	3 (15%)	3 (15%)	14 (70%)
	5	2 (9.5%)	0 (0%)	19 (90.5%)
		1	2	3
	3	10 (50%)	2 (10%)	8 (40%)
	4	10 (50%)	3 (15%)	7 (35%)
	5	20 (95.2%)	1 (4.8%)	0 (0%)
		1	2	3
	3	3 (15%)	10 (50%)	6 (30%)
	4	4 (20%)	2 (10%)	14 (70%)
	5	3 (14.3%)	2 (9.5%)	16 (76.2%)

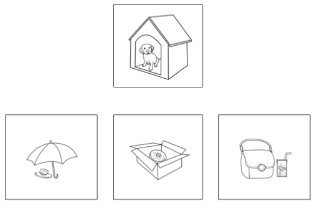
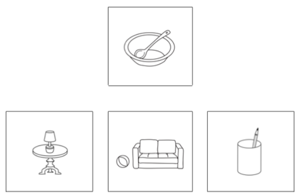
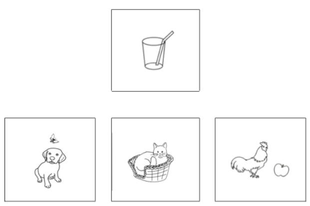
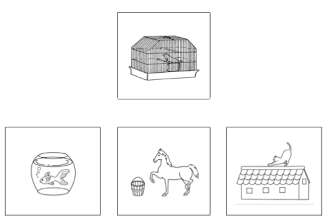
<table>
<tr><td rowspan="4"></td><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>3</td><td>5 (25%)</td><td>5 (25%)</td><td>10 (50%)</td></tr>
<tr><td>4</td><td>8 (40%)</td><td>2 (10%)</td><td>10 (50%)</td></tr>
<tr><td>5</td><td>16 (76.2%)</td><td>0 (0%)</td><td>5 (23.8%)</td></tr>
<tr><td rowspan="4"></td><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>3</td><td>5 (25%)</td><td>11 (55%)</td><td>4 (20%)</td></tr>
<tr><td>4</td><td>3 (15%)</td><td>16 (80%)</td><td>1 (5%)</td></tr>
<tr><td>5</td><td>3 (14.3%)</td><td>17 (81%)</td><td>1 (4.8%)</td></tr>
<tr><td rowspan="4"></td><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>3</td><td>3 (15%)</td><td>10 (50%)</td><td>7 (35%)</td></tr>
<tr><td>4</td><td>3 (15%)</td><td>3 (15%)</td><td>14 (70%)</td></tr>
<tr><td>5</td><td>1 (4.8%)</td><td>0 (0%)</td><td>20 (95.2%)</td></tr>
<tr><td rowspan="4"></td><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>3</td><td>4 (20%)</td><td>12 (60%)</td><td>4 (20%)</td></tr>
<tr><td>4</td><td>1 (5%)</td><td>14 (70%)</td><td>5 (25%)</td></tr>
<tr><td>5</td><td>3 (14.3%)</td><td>17 (81%)</td><td>1 (4.8%)</td></tr>
<tr><td rowspan="4"></td><td></td><td>1</td><td>2</td><td>3</td></tr>
<tr><td>3</td><td>6 (30%)</td><td>5 (25%)</td><td>9 (45%)</td></tr>
<tr><td>4</td><td>3 (15%)</td><td>3 (15%)</td><td>14 (70%)</td></tr>
<tr><td>5</td><td>1 (4.8%)</td><td>1 (4.8%)</td><td>19 (90.5%)</td></tr>
</table>

		1	2	3
	3	9 (45%)	8 (40%)	3 (15%)
	4	4 (20%)	13 (65%)	3 (15%)
	5	1 (4.8%)	20 (95.2%)	0 (0%)
		1	2	3
	3	8 (40%)	5 (25%)	7 (35%)
	4	14 (70%)	1 (5%)	5 (25%)
	5	21 (100%)	0 (0%)	0 (0%)

(d) Rich-to-Rich condition

Spatial Analogy Item	Age	Option		
		1	2	3
	3	9 (45%)	11 (55%)	0 (0%)
	4	7 (35%)	4 (20%)	9 (45%)
	5	5 (25%)	4 (20%)	11 (55%)
		1	2	3
	3	8 (40%)	11 (55%)	1 (5%)
	4	5 (25%)	9 (45%)	6 (30%)
	5	4 (20%)	11 (55%)	5 (25%)
		1	2	3
	3	4 (20%)	8 (40%)	8 (40%)
	4	2 (10%)	4 (20%)	14 (70%)
	5	3 (15%)	2 (10%)	15 (75%)

		1	2	3
	3	2 (10%)	15 (75%)	2 (10%)
	4	9 (45%)	8 (40%)	3 (15%)
	5	7 (35%)	4 (20%)	9 (45%)
		1	2	3
	3	8 (40%)	10 (50%)	2 (10%)
	4	1 (5%)	5 (25%)	14 (70%)
	5	8 (40%)	6 (30%)	6 (30%)
		1	2	3
	3	6 (30%)	12 (60%)	2 (10%)
	4	12 (60%)	6 (30%)	2 (10%)
	5	10 (50%)	5 (25%)	5 (25%)
		1	2	3
	3	7 (35%)	6 (30%)	7 (35%)
	4	6 (30%)	13 (65%)	1 (5%)
	5	7 (35%)	10 (50%)	3 (15%)
		1	2	3
	3	9 (45%)	6 (30%)	5 (25%)
	4	6 (30%)	4 (20%)	10 (50%)
	5	7 (35%)	4 (20%)	9 (45%)

		1	2	3
	3	2 (10%)	15 (75%)	2 (10%)
	4	9 (45%)	8 (40%)	3 (15%)
	5	5 (25%)	11 (55%)	4 (20%)
		1	2	3
	3	6 (30%)	8 (40%)	6 (30%)
	4	3 (15%)	2 (10%)	15 (75%)
	5	8 (40%)	4 (20%)	8 (40%)
		1	2	3
	3	3 (15%)	15 (75%)	2 (10%)
	4	5 (25%)	12 (60%)	3 (15%)
	5	1 (5%)	15 (75%)	4 (20%)
		1	2	3
	3	7 (35%)	5 (25%)	8 (40%)
	4	12 (60%)	3 (15%)	5 (25%)
	5	14 (70%)	4 (20%)	2 (10%)

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