Published in final edited form as:
Dev Sci. 2011 November ; 14(6): 1417–1430. doi:10.1111/j.1467-7687.2011.01088.x.

Children's spatial thinking: Does talk about the spatial world matter?

Shannon M. Pruden[1], **Susan C. Levine**[2], and **Janellen Huttenlocher**[2]
[1]Florida International University
[2]The University of Chicago

Abstract

In this paper we examine the relations between parent spatial language input, children's own production of spatial language, and children's later spatial abilities. Using a longitudinal study design, we coded the use of spatial language (i.e., words describing the spatial features and properties of objects; e.g., big, tall, circle, curvy, edge) from child age 14 to 46 months in a diverse sample of 52 parent-child dyads interacting in their home settings. These same children were given three non-verbal spatial tasks, items from a Spatial Transformation task (Levine et al., 1999), the Block Design subtest from the WPPSI-III (Wechsler, 2002), and items on the Spatial Analogies subtest from Primary Test of Cognitive Skills (Huttenlocher & Levine, 1990) at 54 months of age. We find that parents vary widely in the amount of spatial language they use with their children during everyday interactions. This variability in spatial language input, in turn, predicts the amount of spatial language children produce, controlling for overall parent language input. Furthermore, children who produce more spatial language are more likely to perform better on spatial problem solving tasks at a later age.

Keywords

Spatial thinking; spatial language; language-thought relation; preschool children; longitudinal study

Research findings have linked variations in early language input to individual differences in children's later language and literacy skills (Evans & Shaw, 2008; Hart & Risley, 1995; Huttenlocher, Haight, Bryk, Seltzer & Lyons, 1991; Huttenlocher, Vasilyeva, Waterfall, Vevea & Hedges, 2007). Most of these studies focused on the global aspects of language input children receive, including the overall quantity of speech children hear from their parents, the vocabulary diversity of parent speech, or the syntactic complexity of the speech. For example, variations in the quantity of language that parents provide to their children have been shown to predict children's later cognitive and language abilities (Bornstein, Haynes & Painter, 1998; Haden & Ornstein, 2009; Hart & Risley, 1995; Huttenlocher et al., 1991; Huttenlocher, Vasilyeva, Cymerman & Levine, 2002; Hoff & Naigles, 2002; Hoff-Ginsberg, 1998; Naigles & Hoff-Ginsberg, 1998; Pan, Rowe, Singer & Snow, 2005; Rowe, 2008; Weizman & Snow, 2001).

Much less is known about whether exposure to particular vocabulary items promotes thinking about the concepts those words encode. In fact, only recently have researchers examined whether production of specific sets of words (e.g., number terms, mental state

Corresponding Author: Shannon M. Pruden, Department of Psychology, Florida International University, DM 296A, 11200 SW 8th Street, Miami, FL 33199. shannon.pruden@fiu.edu.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

words, etc.) predict children's later cognitive skills in the related domain (Harris, de Rosnay & Pons, 2005; Levine, Suriyakham, Huttenlocher, Rowe & Gunderson, 2011; Lohmann & Tomasello, 2003; Meins, Fernyhough, Wainwright, Gupta, Fradley & Tuckey, 2002; Pyers & Senghas, 2009; Taumoepeau & Ruffman, 2006). Research on parent's naturalistic production of number words, for example, shows that children who hear a lot of these word types between 14 and 30 months of age have a better understanding of cardinal number at 46 months of age (Levine et al., 2011).

In the current study, we explore whether amount of parent use of spatial language predicts not only children's spatial language but also children's performance on nonverbal spatial tasks. In view of findings that show spatial thinking is an important predictor of STEM (Science, Technology, Engineering, and Mathematics) achievement and careers (e.g., Humphreys, Lubinski & Yao, 1993; Shea, Lubinski & Benbow, 2001; Wai, Lubinksi & Benbow, 2009), it is important to explore the kinds of early inputs that are related to spatial thinking. We examine a particular subset of spatial words, in particular those that refer to spatial features and properties of objects, including words that describe the dimensions of objects (e.g., *big, little, tall, fat*, etc.), the shapes of objects (e.g., *circle, rectangle, octagon, triangle*, etc.), and the spatial properties of objects (e.g., *bent, curvy, flat, edge, pointy*, etc.). We characterize the variability in parents' naturalistic use of these words when their children are 14 to 46 months of age and examine the extent to which these variations are independent of variations in overall language input. We then examine the relation of these input variations to children's own use of these spatial terms, and their later success on a variety of spatial tasks.

Our interest in the relation between spatial language and spatial cognition grew out of a more general debate on the relation between language and thought (see Bowerman & Levinson, 2001; Gentner & Goldin-Meadow, 2003; Gumperz & Levinson, 1996, for recent revivals of this topic). Theories about how language affects thought range from the strong Whorfian position that language plays a determinative role in thinking (Whorf, 1956), to "weaker" positions that language augments our capacity to think, represent and reason about the world (e.g., Gentner, 2003) and influences how we categorize our world (e.g., Bowerman & Choi, 2003). Recent research on the language-thought relation has focused on the domain of space and has mainly involved cross-linguistic comparisons. This research shows that there are differences in how languages carve up and lexicalize space (Bowerman, 1996; Talmy, 1985), and that these differences are related to variations in spatial thinking (e.g., Pederson, Danziger, Wilkins, Levinson, Kita & Senft, 1998). Here, we take a different approach by looking at input variations within in a single language, and exploring whether the amount of spatial language young English-speaking children hear is associated with more developed spatial skills in those children.

Some theorists argue that exposure to spatial language can augment one's ability to think about the spatial world. For example, Gentner asserts that, "relational labels invite the child to notice, represent, and retain structural patterns of elements" (Gentner & Loewenstein, 2002, p.103). In support of this position, experimental studies show that children who hear spatial language while performing spatial tasks do better on those tasks than those who hear non-spatial terms rather than these spatial terms (Casasola, Bhagwat & Burke, 2009; Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Kotovsky & Gentner, 1996; Rattermann & Gentner, 1998; Rattermann, Gentner & DeLoache, 1990; Szechter & Liben, 2004).

Existing experiments examining the relation of spatial language to spatial thinking have mainly tested whether spatial language input, that immediately precedes a spatial task, is related to children's performance on that task. For example, Loewenstein and Gentner

(2005) showed that preschool children were better at finding a target item in one of three possible locations when the experimenter used related spatial language to describe the target's location (e.g., "I'm putting the winner *on/in/under* the box," or "I'm putting the winner *at the top of/at the middle of/at the bottom* of the box") than when the target's location was described with deictic, non-spatial language (e.g., "I'm putting the winner here"). Dessalegn and Landau (2008) recently found that 4-year-olds who heard spatial language specifying direction (e.g., "The red is on the left") during a complex matching task were more apt to bind and remember color and location information than those who heard language not specifying directional information (e.g., "the red is touching the green"). Szechter and Liben (2004) report evidence that even spatial terms that are not highly relevant to the later spatial task predict children's spatial performance. In a laboratory task, they found that 5-year-old children whose parents use spatial language to highlight spatial relations in picture books, including language about object size and location, were better at correctly ordering sequences of photographs using spatial information, such as viewing distance right after the book reading interaction.

There is also evidence that children's use of spatial language is related to their spatial skills. Two studies have reported a link between children's spatial lexicons and their proficiency on spatial tasks (Hermer-Vasquez, Moffet & Munkholm, 2001; Shusterman, 2006). Both studies evaluated whether children could successfully search for a hidden object after being disoriented, commonly referred to as a spatial reorientation task. Hermer-Vasquez and colleagues found that children who produced the spatial terms "left" and "right" correctly during a language production task were more likely to reorient themselves to search in the correct corner for a hidden object after disorientation than their peers who did not produce these words (also see Pyers, Shusterman, Senghas, Spelke & Emmorey, 2010 for evidence that success on this spatial reorientation task in adult Nicaraguan Sign Language signers is modulated by the acquisition of spatial language). Similarly, Shusterman demonstrated that 4-year-olds who were taught and later showed correct comprehension of the terms "left" and "right" in the laboratory performed better on the same spatial reorientation task than those who were not taught these terms. These results suggest that children's use of spatial words is a predictor of their success in performing a spatial task.

Taken together, these experimental studies suggest that children who hear and produce spatial language during various spatial-cognitive tasks often perform better on those tasks than those who do not receive or produce spatial language. Our study takes this experimental research one step further by looking at naturalistic spatial language over a long period of time to see if its use is related to children's performance on spatial tasks (e.g., mental rotation, block design and spatial analogies) that are not as obviously related to the spatial words as those that have been used in experimental studies.

In the present study, we track spatial language production in both children and their primary caregivers longitudinally, between 14 and 46 months of age, while they interacted naturalistically in their homes and assessed children's spatial skills at 54 months of age. Our goal was to explore the variability in both parent's and children's spatial language production through 46 months of age, and investigate the extent to which variability in parent spatial language is related to variability in child spatial language, controlling for non-spatial language or what we refer to as "other talk." In addition, we examine the extent of individual differences in children's performance on three non-verbal spatial tasks, including a spatial transformation task, a block design task and a non-verbal spatial analogies task and whether performance levels on these three tasks are correlated. Finally, we explore the relation between parent spatial language input, children's spatial language production, and children's later performance on these three non-verbal spatial tasks.

We hypothesize that parents' spatial language use will predict children's spatial language use, which in turn, will predict children's later performance on spatial tasks. By using three different spatial tasks as outcome measures, we are able to explore whether spatial language is generally predictive of children's performance on spatial tasks, or whether this relation varies, depending on particular aspects of the spatial task. Importantly, each of the spatial tasks taps different spatial skill sets, with the Spatial Transformation task assessing children's ability to mentally rotate or translate shapes, the Spatial Analogies task assessing children's ability to match spatial relations across different objects, and the Block Design task assessing children's ability to reconstruct spatial patterns. It is possible that spatial language will help children attend to spatial relations that are critical for the performance of all of these tasks. Alternatively, it is possible that spatial language will be more important for spatial tasks with certain characteristics. For example, spatial language may be more critical for the performance of spatial tasks where the coding of verbalizable spatial features and relations is important. If this is the case, we may see a stronger relation between spatial language and children's performance on the Spatial Transformation task and the Spatial Analogies task than on the WPPSI-III Block Design subtest, which requires children to copy spatial patterns that are composed of a limited number of spatial elements (red block faces, white block faces, and block faces that are half red and half white, divided along the diagonal).

Method

Participants

The sample consisted of 52 typically developing children (26 males; 26 females) and their primary caregivers (50 mothers; 2 fathers). These parent-child dyads were part of a larger, longitudinal language study in which 64 families participated. All children were from monolingual, English-speaking homes in the greater Chicago area. Twelve additional dyads were excluded from the study because they missed more than one of the nine sessions between 14 and 46 months ($n = 6$), or they did not complete our battery of spatial tasks at 54 months of age ($n = 6$). Children who did not complete two out of three spatial tasks were omitted from final analysis ($n = 3$: two children did not complete the Spatial Analogies test and one did not complete the Block Design subtest because they refused to do the task).

Families were recruited for the longitudinal study via an advertisement in a parenting magazine and through mailings. Interested families completed a screening interview in which they were asked about their demographic information, including family income, parents' education, parents' occupation, race/ethnicity, and their child's sex. Families selected to participate in the longitudinal study represented the diversity of the Chicago area as assessed by their demographic information, with the caveat that all parents were native English speakers and participating families spoke only English in the home. Families varied in their ethnic/racial backgrounds, with 42% of the families being Hispanic ($n = 5$), Asian American ($n = 2$), African American ($n = 9$), or mixed race ($n = 6$). Families also varied in their income and education. Table 1 summarizes the demographic information of the participating families by their income and educational backgrounds. The average family income for our sample fell within the $50,000 to $75,000 range and the average number of years of education was 15.58 ($SD = 2.25$).

Materials

Three non-verbal spatial tasks were administered to children at 54 months of age: a Spatial Transformation task (Levine, Huttenlocher, Taylor & Langrock, 1999), the Block Design subtest of the Wechsler Preschool and Primary Scale of Intelligence – Third Edition (WPPSI-III; Wechsler, 2002), and a Spatial Analogies test based on the Primary Test of

Cognitive Skills (PTCS; Huttenlocher & Levine, 1990). In addition to these spatial tasks, children's comprehension of language was assessed at 54 months using the Peabody Picture Vocabulary Test, 3rd Edition (Dunn & Dunn, 1997).

Spatial Transformation task—An abbreviated version of the Children's Mental Transformation Task used by Levine et al. (1999) contained 10 items assessing children's ability to mentally transform two shapes to make a whole. On each item children were shown four shapes (right picture; Figure 1) and two target pieces (left picture; Figure 1). Children were asked to select a shape that the two target pieces would make if they were put together. For each item, the child received the following instructions from the experimenter, "Look at the pieces. Now look at these shapes. If you put the pieces together, they will make one of these shapes. Point to the shape the pieces make." Six items had pieces that were rotated 45° from each other (rotation items), while the other four items had pieces that were translated from each other through a horizontal or diagonal displacement (translation items). Thus, some items required only a rotation while others required a translation of the pieces. The first item children selected was scored as either correct or incorrect and every correct item received 1 point. Children completed all 10 items yielding a possible score range of 0 to 10 points.

Block Design subtest of WPPSI-III—The Block Design subtest from the WPPSI-III was administered according to the directions in the WPPSI-III instruction manual. Using three-dimensional red and white colored blocks, children were asked to recreate a design that was either modeled by the experimenter or shown pictorially. Children were administered items until the stopping criterion had been reached (i.e., three consecutive incorrect responses). There were 20 items on this test and the maximum raw score was 40, if all items were completed correctly and within a specified amount of time.

Spatial Analogies test—The Spatial Analogies test was adapted from the Primary Test of Cognitive Skills (Huttenlocher & Levine, 1990). This adapted version contained 12 of the 16 spatial items found on the analogies subtest of the PTCS and was used to assess children's ability to perceive the analogous relation between two spatial figures. In this task, children were shown an array of four pictures and a target picture and were instructed by the experimenter to select the picture that "goes best" with the target picture. For half of the items a verbal, spatial label could not easily be mapped onto the spatial relation depicted, however for the other half one could readily map a spatial word to the relation depicted in the picture (Figure 2; e.g., "bird *above* the tree"). Most of these spatial labels referred to either spatial locations (i.e., above, between, in front of, next to) or were words that neither parents nor children in our sample used (i.e., symmetrical). Children completed all 12 items and received one point for every correct item, yielding a possible score range of 0 to 12 points.

Peabody picture vocabulary test—The Peabody Picture Vocabulary Test, Version III (PPVT-3; Dunn & Dunn, 1997), a standardized measure of children's receptive vocabulary, was used as a proxy to assess verbal intelligence (Childers, Durham & Wilson, 1994). Scores for each child are age-based standard scores based on a mean score of 100 and the standard deviation, 15.

Procedure

This study was part of a larger longitudinal study in which parent-child dyads were visited in their homes every four months beginning at 14 months of age. In the current study, we focused on the language of children and their primary caregivers between the ages of 14 months and 46 months (9 visits). During each visit, parent-child dyads were videotaped for

90 minutes and asked to engage in their everyday, daily routines. Dyads were not given specific objects or toys to play with, rather, they were asked to spend their time as they normally would. During typical visits dyads often engaged in toy play, book reading, and meal or snack time, but were free to do whatever they wanted. When parents and children were engaging in different activities (e.g., child was playing with toys while mom was in the kitchen preparing a snack), the video camera continued to record the child's behavior. In addition to these nine visits, we evaluated children's performance on three non-verbal spatial tasks and the PPVT-3 administered when the children were 54 months of age.

Coding and dependent variable—Both children's and parent's speech were transcribed at each of the nine time points (i.e., 14-, 18-, 22-, 26-, 30-, 34-, 38-, 42-, and 46-months) by trained research assistants using the procedures outlined in Huttenlocher et al. (2007). Reliability in transcription was achieved by having a second research assistant independently code at least 20% of speech, yielding reliability for the transcription of speech, $r > .95$.

These transcriptions were then coded to assess use of language about spatial features and properties of objects. While many other aspects of speech are spatial in nature, we targeted only those terms that encoded the *spatial properties and features* of objects and people (e.g., shape, size, and featural information of the object; i.e., the "what" aspects of spatial information). Other spatial terms, including those terms that encode the "where" aspects of spatial information (i.e., location and direction terms such as *between*, *into*, and *forward*) were not entered as predictors in further analyses because these words were highly correlated with children's overall language use (e.g., $r = .92$, $p \leq .05$ for tokens). This high correlation ensures collinearity of the "where" spatial terms with overall language use, which would invalidate any mediation analysis assessing the relation between "where" spatial terms and the behavioral measures. Note, this was not true for "what" spatial terms as these terms were less related to children's overall language use ($r = .57$, $p \leq .05$).

We used the System for Analyzing Children's Language About Space (Cannon, Levine & Huttenlocher, 2007) to identify and code our targeted spatial words. The three categories of spatial terms we coded are as follows:

Shape terms: words that describe mathematical names of two- and three-dimensional objects and spaces. For example, words such as *circle, triangle, octagon*, and the word, *shape*, were identified as shape terms.

Dimensional adjectives: words that describe the size of objects, people and spaces. For example, words such as *big, little, tall, tiny, small*, and *long*, were classified as dimensional adjectives.

Spatial features terms: words that describe the features and properties of twoand three-dimensional objects, people, and spaces. For example, words in this category include *bent, curvy, edge, side, line*, and *corner*.

Targeted words that were used in a non-spatial manner were not considered as part of our spatial language measures. Usages that were not included consisted of the following: homonyms (e.g., "Are you my *big* boy?" and "You are a *little* angel."), metaphorical uses (e.g., "That took a *long* time" and "You have a *big* heart"), spatial words used in names (e.g., "*Big* Bird" and "*Little* Drummer Boy"), and other spatially ambiguous usages (e.g., "It will only be a *short* walk" might refer to time).

For each child and parent we assessed the cumulative number of *spatial tokens* and *spatial types* used from 14 to 46 months over the three targeted word categories (i.e., dimensions, shapes, and features). Spatial tokens assessed the number of spatial word uses and spatial types assessed the number of unique spatial words used. For example, a child who used the word *big* in a spatial manner five times had 1 spatial type and 5 spatial tokens. We also measured non-spatial language use (i.e., "other talk") for each parent and child by calculating cumulative non-spatial word tokens and types. These variables included the production of all word tokens and word types minus the spatial tokens and spatial types.

Results

Variation in spatial language production and relation to overall language use

Descriptive statistics for children and parents' language use (i.e., other tokens and other types; spatial tokens and spatial types) showed that there was considerable variability in the production of the various word tokens and word types (Table 2). Not surprisingly, some children and some parents used relatively few spatial words between 14 and 46 months of age while others used substantially more. On average, parents said 167.06 ($SD = 120.52$) spatial tokens during the 9 visits (i.e., 810 minutes or 13.5 hours) between child ages 14- and 46-months. The number of spatial tokens used by parents ranged from a low of only 5 spatial tokens to a high of 525 spatial tokens. If one were to extrapolate for a week, based on 8-hour days, it would yield a range of 21 spatial words to 2178 parent spatial words to children, a 100-fold difference. We also saw the same pattern of variability in children, with children producing on average 74.44 ($SD = 45.71$) spatial tokens over the 9 visits, with a range of 4 to 191 spatial tokens. A t-test assessing sex differences on children's cumulative spatial tokens showed only a marginally significant difference in the amount of spatial language used by boys ($M = 85.88$, $SD = 49.03$) and girls ($M = 63.00$, $SD = 39.82$; $F[1,50] = 1.85$, $p = .07$). The same pattern of results held for spatial types, with considerable variability in both parents' and children's use of spatial word types. Table 3 shows the most common spatial words used by parents and by children, broken down by category (i.e., shape terms, dimension terms and spatial feature terms). Only those spatial terms that at least 50% of parents produced by 46 months are included in this table, although all coded spatial terms used by parents were used in our analyses.

In general, those parents and children who produced a lot of spatial word tokens also produced a lot of spatial word types (for children: $r = .80$, $p \leq .001$; for adults: $r = .84$, $p \leq .001$); we use tokens as our dependent variable for all further analysis, although using types yields the same general pattern of results. Further, those parents who produced a lot of non-spatial language, what we called "other tokens" also produced a lot of spatial tokens ($r = .86$, $p \leq .001$). For children, the relation between other tokens and spatial tokens was also significant, but not as highly related ($r = .57$, $p \leq .001$). These findings show that we must control for overall language (i.e., other tokens) when examining the relation between spatial word tokens and children's performance on spatial tasks.

Individual differences in children's non-verbal spatial skills and relation among tasks

Descriptive statistics for children's performance on the three non-verbal spatial tasks (i.e., Spatial Transformation task, Spatial Analogies test, and WPPSI-III Block Design) indicate that there was also a great deal of variability in children's performance on these tasks (see Table 4).

T-tests comparing boys to girls showed no sex differences in children's performance in the WPPSI-III Block Design subtest ($t[49] = 0.71$, $p > .05$) or the Spatial Analogies task ($t[48] = 1.09$, $p > .05$). A significant sex difference was found for children's spatial transformation scores (t[50] = 2.28, $p \leq .05$), with boys ($M = 5.65$, $SD = 1.85$) performing better than girls ($M = 4.46$, $SD = 1.92$).

Significant, positive correlations showed that children's performance levels on the three spatial tasks were related. Thus, children who performed well on the Spatial Transformation test were also likely to do well on the WPPSI-III Block Design subtest ($r = .49$, $p \leq .001$) and the Spatial Analogies task ($r = .39$, $p \leq .01$) and those who performed well on the Spatial Analogies task were likely to do well on the WPPSI-III Block Design subtest ($r = .47$, $p \leq .001$). These correlations remained significant when we controlled for performance on the PPVT-3 suggesting that that these positive relations do not merely reflect a more general intellectual factor (r's > .36, p's ≤ .01).

Relation of parent and child spatial language use

One of our primary questions of interest is whether there was a relation between parent and child spatial language use. Table 5 reports the correlations between children's and parent's language measures and children's performance on our three non-verbal spatial tasks We asked whether parents who use a lot of spatial language have children who use a lot of spatial language, even after controlling for parents' other word tokens. An analysis of parent spatial tokens and child spatial tokens revealed that this was the case ($r = .55$, $p \leq .001$). These results suggest that parents who used a lot of spatial language had children who also produced a lot of spatial language and that this was not merely a bi-product of hearing or producing more language in general, since we controlled for other tokens, in our analysis.

Relation of spatial language production to children's performance on each non-verbal spatial task

We examined whether individual differences in children's performance on each non-verbal spatial task was related to the amount of spatial language children heard. Controlling for parents' other tokens and children's other tokens, parents' spatial tokens were positively related to children's performance on the Spatial Transformation task ($r = 0.27$, $p \leq .05$) and the Spatial Analogies test ($r = 0.30$, $p \leq .05$), but not to children's performance on the WPPSI-III Block Design subtest ($r = 0.09$, $p > .05$). Thus, children who heard more spatial language from their primary caregivers performed significantly better on two out of three spatial tasks, the Spatial Transformation task and Spatial Analogies test, even after controlling for overall parent language use or "other tokens".

We next tested our hypothesis that the link between parent spatial language and children's performance on the Spatial Transformation task and the Spatial Analogies test were the result of parent spatial language influencing children's spatial language use, which in turn promotes children's attention to spatial aspects of the world and ultimately better spatial thinking. If this is the case, the significant relation between parent spatial language and children's performance on the Spatial Transformation task and the Spatial Analogies test should be mediated by children's spatial language use.

A mediation analysis is a statistical procedure used to examine whether a third (mediating) variable intervenes between a predictor variable and an outcome variable (Iacobucci, 2008). For example, in our study we are interested in assessing whether the relation between parent spatial token production and child performance on the Spatial Transformation, Block Design and Spatial Analogies tasks may be mediated by children's production of spatial tokens. This analysis allows us to determine whether parent spatial language directly influences child spatial skill, or alternatively whether parent spatial language influences child spatial language, which then influences child spatial skill. Notably, a mediation analysis requires a number of prerequisite assumptions to be met, including: (1) that there is a significant relation between the independent variable (i.e., parent spatial tokens) and the mediating variable (i.e., child spatial tokens); (2) that there is a significant relation between the independent variable (i.e., parent spatial tokens) and the dependent variable (i.e., child's performance on Spatial Transformation, WPPSI-III Block Design and Spatial Analogies tests); and (3) that there is a significant relation between the mediating variable (i.e., child spatial tokens) and the dependent variable (i.e., child's Spatial Transformation, WPPSI-III Block Design and Spatial Analogies scores). Once these necessary correlations are established, the mediation analysis can proceed through linear regression analysis with child spatial tokens as a potential mediator between parent spatial tokens and child scores on the non-verbal spatial task. Using this analysis we were able to ask whether children's own spatial language use was explaining a significant amount of the variance accounted for by the relation of parent spatial language input and children's spatial skill. Results obtained from the mediation models were evaluated using those guidelines outlined by Baron and Kenny (1986).

Spatial Transformation task—Figure 3a shows that all three variables of interest, parent spatial tokens, child spatial tokens, and child spatial transformation scores, were significantly, positively correlated with each other, thus meeting the necessary prerequisite for a mediation analysis (r's > .27, p's ≤ .05; after controlling for parent's other tokens and children's other tokens).

Regression analysis established that parent spatial tokens significantly predicted children's spatial transformation scores ($\beta = .93$, $t = 3.81$, $p \leq .001$). Figure 3b shows the strength of this direct effect (path c) of parent spatial language input on children's later Spatial Transformation performance. When children's spatial tokens were included as a potential mediator, the path coefficient (c') was reduced substantially ($\beta = .36$, $t = 1.11$, $p > .05$), suggesting that parent spatial language influences children's Spatial Transformation performance via children's own spatial language use (Figure 3c)[1]. This model accounted for over 31% of the variance (based on R^2) on children's spatial transformation scores. A bias-corrected bootstrapping procedure (Preacher & Hayes, 2004) gave a 95% confidence interval of 0.19 to 1.07. This bias corrected confidence interval did not contain zero, suggesting that the reduction in the direct relation between parent spatial tokens and children's spatial transformation scores was significant. Taken together, these results indicate that the relation between parent spatial language and children's performance on the Spatial Transformation task was accounted for by children's use of spatial language. It should be noted that when we considered only the earlier time points (14 to 30 months) or only the later time points (34 to 46 months) in computing cumulative parent and child spatial tokens, results of this analysis were similar, but not as strong as when spatial tokens were cumulated from 14 to 46 months.[2]

Spatial Analogies test—As was the case for the Spatial Transformation task, Figure 4a shows that all three variables of interest, parent spatial tokens, child spatial tokens, and child spatial analogies scores, were significantly, positively correlated with each other, meeting the prerequisites for mediation analyses (r's > .30, p's ≤ .05; after controlling for parent's other tokens and children's other tokens).

[1]Entering "other" tokens in the model as covariates revealed no significant effect on children's spatial transformation scores (children's tokens, $\beta = -0.3$, $t = -0.09$, $p = .93$; parents' tokens, $\beta = 0.68$, $t = 0.15$, $p = .88$). Similarly, entering child's sex in the model as a covariate revealed no significant effect on children's spatial transformation scores ($\beta = -0.59$, $t = -1.16$, $p = .25$).

[2]Repeating this mediation analysis using either cumulative spatial tokens from 14- to 30-months ("early talk") or 34- to 46-months ("late talk") showed that these models accounted for less variance in children's spatial transformation scores, $R^2 = .27$ and $R^2 = .21$, respectively, than the full model, 14- to 46-months, $R^2 = .31$.

Figure 4b and 4c illustrate the direct and indirect influence of parent spatial tokens on children's spatial analogies scores, with child spatial tokens as the potential mediator between these two variables. The direct effect (*c*) of parent spatial tokens on children's spatial analogies scores was significant (Figure 4b; $\beta = 1.27$, $t = 3.68$, $p \leq .001$). Including children's spatial tokens as a potential mediator reduced the direct effect (*c*') of parent spatial tokens on children's spatial analogies scores (Figure 4c; $\beta = .57$, $t = 1.22$, $p > .05$).[3] This model accounted for 29% of the variance (based on R^2) on children's spatial analogies scores. These results suggest parent spatial language influences children's spatial analogies scores indirectly via our mediating variable, children's spatial language production. Using the bias-corrected bootstrapping procedure, the 95% confidence interval did not contain zero (95% CI: 0.05 to 1.42) suggesting that this reduction in the direct relation between parent spatial tokens and children's spatial analogies scores was significant. When we again considered only the earlier time points (14 to 30 months) or only the later time points (34 to 46 months) in computing cumulative parent and child spatial tokens, results of this analysis were similar, but not as strong as when spatial tokens were cumulated from 14 to 46 months.[4]

Predictors of children's WPPSI-III Block Design performance—A partial correlation, as reported previously, revealed that the variable, parent *spatial tokens*, was not significantly correlated with children's performance on the Block Design task after we controlled for parent other tokens ($r = 0.09$, $p > .05$) – a key prerequisite required for a mediation analysis (Figure 5). Thus, mediation analysis was not an appropriate statistic for analyzing children's Block Design scores, as there was no relation to mediate.

To determine the best predictors of children's performance on the Block Design task, we performed multiple linear regressions. These regressions were used to establish the amount of variance in children's block design scores explained by each of the following variables: (1) parent's *other tokens*, (2) parent's *spatial tokens*, (3) children's *other tokens*, and (4) children's *spatial tokens*. Regressions were also used to assess which variables were significant predictors of the children's Block Design scores. For each regression model, two types of statistics are presented. The first is the standardized partial regression coefficient, β. This coefficient indicates the change in standard deviation in children's Block Design scores for every one standard deviation change in the predictor variable (e.g., children's spatial tokens, etc.). The second statistic reported is adjusted R^2. This statistic indicates the total amount of variance (adjusted for multiple predictors) accounted for by each of the regression models.

The regressions presented in Table 6 show which variables were significant predictors of children's performance on the WPPSI-III Block Design test. In Model 1 we found that the parent's *other tokens* variable, our measure of parent overall language use and talkativeness, was a significant predictor of children's performance on Block Design ($\beta = .27$, $p \leq .05$), accounting for 5.5% of the variability in children's scores (adjusted R^2 reported; Model 1, Table 6). However, when we added parent's *spatial tokens* in Model 2 we found that neither parent's spatial tokens ($\beta = .22$, $p > .05$) nor parent's other tokens ($\beta = .09$, $p > .05$) were significant predictors of children's performance on the Block Design test (adjusted R^2 = 4.9%; Model 2, Table 6), the same result we captured in the partial correlation between parent spatial tokens and children's Block Design scores. In Model 3, we assessed whether

[3]Controlling for "other" tokens does not significantly alter the pattern of results. Including "other" tokens in the model as covariates showed that neither children's "other" tokens ($\beta = -0.14$, $t = -0.35$, $p = .73$) nor parent's "other" tokens ($\beta = -0.13$, $t = -0.19$, $p = .85$) had an effect on children's spatial analogies scores.

[4]Repeating this mediation analysis using either cumulative spatial tokens from 14- to 30-months ("early talk") or 34- to 46-months ("late talk") showed that these models accounted for less variance in children's spatial analogies scores, $R^2 = .17$ and $R^2 = .26$, respectively, than the full model, 14- to 46-months, $R^2 = .29$.

children's other tokens would add any predictive power. This regression revealed children's other tokens did not significantly predict children's later performance on the WPPSI-III Block Design test (β = .17, p > .05; adjusted R^2 = 5.6%; Model 3, Table 6). Finally, in Model 4, we tested whether children's use of spatial language (as assessed by *spatial tokens*) predicted their performance on the Block Design task, even after controlling for parent and child other tokens and parent spatial tokens. This model revealed that children's *spatial tokens* remained a significant predictor of their performance on the Block Design task (β = .52, $p \leq .05$, adjusted R^2 = 14.5%; Model 4, Table 6). These results indicate that just as for the Spatial Transformation and the Spatial Analogies tests, children's use of spatial language is a significant predictor of their later performance on the WPPSI-III Block Design task, even after controlling for children's and parent's overall language use. Repeating these models with either early time points (14 to 30 months) or only the later time points (34 to 46 months) in computing cumulative parent and child spatial tokens shows similar patterns, however the "late" spatial talk model accounted for less variance (adjusted R^2 = .032) than the full model, whereas the "early" spatial talk model accounted for roughly the same amount of variance (adjusted R^2 = .18) in children's Block Design scores when compared to the full model (adjusted R^2 = .15). Thus, in contrast to the findings for the Spatial Transformation task and the Spatial Analogies test, these results raise the possibility that children's earlier uses of spatial language may be more predictive of their later performance on the Block Design task than their later spatial talk.

Discussion

Our longitudinal study examined three questions. The first concerned variability in children and parents' spatial talk and the relation between the two, controlling for "other talk." Consistent with prior research, our results revealed substantial variability in the production of spatial language by both children and their primary caregivers (Bates, Bretherton & Snyder, 1988; Bloom, 1991; Clark, 2003; Naigles, Hoff & Vear, 2009; Pruden & Levine, 2011) and a significant relation between parents' spatial language use and children's spatial language use, controlling for parent and child "other talk." The current study is among only a few to examine parent input as it relates to the development of children's spatial language and spatial thinking (Szechter & Liben, 2004). By focusing on talk about the size and shapes of objects, we show that parents who provide more talk about these aspects of space have children who do the same. Our second question concerned variation in children's performance on three nonverbal spatial tasks and whether children who perform well on one of these tasks are likely to perform well on all of these tasks. Our findings show modest positive correlations among the three tasks, even controlling for performance on a verbal test, the PPVT-3, and substantial individual variation in performance level on three non-verbal spatial tasks.

These findings enabled us to address our third and main question, which concerns the relation of parent and child spatial language to children's spatial thinking. We hypothesized that parents' spatial language use with their young children would predict children's spatial language production, which in turn would predict their later spatial skills. As predicted, on the Spatial Transformation and the Spatial Analogies tests, our analyses showed that children's use of spatial language mediated the positive relationship between parent spatial language input and children's performance on these two tasks. In addition, children's performance on the WPPSI-III Block Design subtest was predicted by children's cumulative production of spatial tokens between 14 and 46 months, even after controlling for their overall other talk and their parents' spatial and other talk. Taken together, these results suggest that children's talk about space early in development is a significant predictor of their later spatial thinking.

The current results extend those of prior studies examining the relation between spatial language and spatial thinking in several ways. First, the present study shows that there is variability in exposure to and use of spatial language over the 32-month time period between 14 and 46 months of age in everyday, naturalistic interactions that occur in the home environment. Indeed, this is one of only a handful of studies to document variability in the use of spatial and relational words longitudinally (Choi & Bowerman, 1991; Fenson et al., 1994; Internicola & Weist, 2003; Naigles et al., 2009). Second, as mentioned previously, most prior studies have examined the relation of spatial language and spatial thought by examining cross-linguistic variations in the ways different languages lexicalize spatial relations (e.g., Pederson et al., 1998). We instead focused on variations in exposure and production of spatial language within a single language, English, and found a relation between children's spatial language use and their performance on three spatial tasks that do not require a verbal response. Finally, previous research examining the relation of spatial language to spatial thinking mainly presented spatial terms that: (a) were highly relevant to the spatial task (e.g., using the word "middle" to describe the middle location) and; (b) directly preceded the spatial task in time (i.e., word was said minutes before spatial task). In contrast, we showed that a broad range of spatial words, including words not necessarily directly related to our spatial tasks, predicted children's success on these tasks. Moreover, the samples of spatial language were gathered across multiple time points, spanning almost 3 years, suggesting that the relation of language and spatial performance are not simply due to priming before the task.

Our findings are consistent with the following developmental trajectory. During everyday, parent-child interactions, parents vary widely in the amount of spatial language they use with their children. This variability in spatial language input is, in turn, predictive of the amount of spatial language children use. That is, between 14 and 46 months, those children who have been exposed to a lot of spatial language input are far more likely to produce spatial language themselves. Furthermore, children who produce more spatial language are more likely to perform better on spatial problem solving tasks somewhat later, at 54 months of age. The correlational pattern obtained from this naturalistic study is consistent with causal as well as non-causal explanations of the relationship between children's spatial language and their performance on spatial tasks.

A possible causal story is that rich spatial language has a general positive effect on spatial cognition, promoting children's attention to spatial information and their ability to solve spatial problems (Casasola, 2005; Gentner & Goldin-Meadow, 2003). Rich spatial language can also be useful in the specific problem solving contexts that we present. In the context of the children's Spatial Transformation task, enhanced ability to verbally describe the shapes may result in better performance by supporting more robust encoding of spatial information. For example, a study with adults who were given the task of deciding whether two molecules are identical shows that rich representations of these molecules in chemistry experts results in a decreased need to mentally rotate the molecules (Stieff, 2007). Similarly, children with rich spatial language may be able to decrease the cognitive load involved in mentally transforming the shapes because they are able to form a better representation of the shapes by using spatial language to describe key features of the shapes that differentiate the target shape from foil alternatives.

A similar mechanism may also explain the relation between spatial language and children's performance on the Spatial Analogies task. An enhanced ability to verbally describe spatial features and spatial relations may lead to an increased awareness and better encoding of spatial features and relations (Gentner, 1988; Gentner, Simms & Flusberg, 2009). According to Gentner's relational shift hypothesis (1988), young children initially focus on objects and only later shift to a reliance on spatial relations in analogical tasks. One tool that appears to aid children in moving from a reliance on objects to relations is relational or spatial language (Gentner, 2003; Genter & Ratterman, 1991; Gentner et al., 2009). Under this view, those children who hear and produce more spatial language would have an advantage on the Spatial Analogies task as they may be more apt to notice the spatial relations required to succeed on our Spatial Analogies task. Those children exposed to and producing less spatial language may be less likely to note these spatial relations, but instead focus on object properties, such as object kind.

Unlike the other two non-verbal spatial tasks, parent's spatial language use was not related to children's later WPPSI Block Design scores. Why might this be the case? One possibility is that verbal coding of spatial features (e.g., shape, size, and spatial feature terms) is simply more useful for tasks that require one to mentally manipulate, rotate or compare images (i.e., the Spatial Transformation and Spatial Analogies tasks), than for performing the Block Design task. On the Block Design task, the individual elements involved are limited to solid red block faces, solid white block faces, or block faces that are half red and half white, with the block divided along the diagonal. As a result, the spatial terms that might be useful to the child in reconstructing these patterns may be more limited than for the other two spatial tasks and as our "early" versus "late" spatial talk models suggest, may be limited to the child's early spatial lexicon. In fact, it may be the case that those spatial words not examined in the present study, including location, direction and orientation (e.g., next to, above, below) terms are the ones that are most useful to the child in solving problems on the Block Design task. It is also likely that spatial tasks vary in terms of the extent to which spatial language and spatial visualization skills (i.e., imagery, spatial memory, and the ability to carry out mental transformations) are used, and that the differential use of particular kinds of processes may have influenced our pattern of results. Indeed, our findings provide a starting point for the design of studies aimed at increasing our understanding of the types of spatial tasks and problem solving strategies that are and are not influenced by spatial language knowledge.

While the amount of variance in children's spatial skills that was accounted for by our spatial language predictors was statistically significant, there was additional unexplained variance (e.g., explained variance for Spatial Transformation task $R^2 = .31$, for Spatial Analogies $R^2 = .29$, for WPPSI-III Block Design $R^2 = .15$). Thus, there may be additional factors that contribute to variability in the outcomes such as engagement in spatial play. For example, recent research suggests that the amount of puzzle play children engage in early in life is predictive of their later performance on a mental rotation task (Levine, Ratliff, Huttenlocher & Cannon, 2011). It may be the case that children's engagement in spatial activities such as puzzle play, which co-occurs with a lot of spatial language, is causally related to better spatial abilities. Under this account, spatial activities promote better spatial thinking and children simply learn more spatial language as a by-product of engaging in these spatial activities. Moreover, it could be that early spatial ability or early interests in spatial activities leads parents to engage children in more spatial activities and to provide them with more spatial language. In this case, rather than exposure to spatial language or spatial activities leading to improvement in spatial skill, children's pre-existing spatial skills and interests lead to more exposure to spatial language and activities. Finally, a third variable could explain the relation of spatial language to spatial thinking. For example, parents' gesture during spatial talk predicts children's spatial language (Cartmill, Pruden, Levine & Goldin-Meadow, 2010) and may also be related to children's later spatial thinking.

An experimental approach is needed to examine whether enhancing children's spatial language leads to improvements in spatial thinking. In such a study, children could be randomly assigned to engage in spatial activities with or without accompanying spatial language and gesture. The key question is whether children in the spatial activity plus spatial language condition show greater improvements on tasks such as the Spatial Transformation task than children in the spatial activity minus spatial language condition, a finding that would demonstrate a causal link between children's spatial language and their spatial cognition.

In summary, the current findings indicate that children's early spatial language is related to parents' use of spatial language. Further, children's spatial language production is a significant predictor of their later spatial skills. Should further research reveal that spatial language not only predicts but also improves children's spatial skills there would be obvious educational implications. In particular, such findings would indicate that talking about the spatial world is a relatively easy way to enhance young children's spatial language as well as their spatial thinking.

Acknowledgments

This research was supported by a National Institute of Child Health and Human Development Grant (P01HD40605) and a National Science Foundation Science of Learning Center Grant (SBE0541957), the Spatial Intelligence Learning Center (SILC), to Susan Levine. Special thanks go to Anthony Dick and four anonymous reviewers for providing comments on earlier drafts of this manuscript. We also thank Kristi Schonwald, Jodi Khan and Jason Voigt for administrative and technical support, and the numerous undergraduate and graduate students at the University of Chicago for their assistance in data collection, transcription and coding. Finally, we would also like to express our deepest gratitude to all of the families that participated in these studies.

References

Balaban MT, Waxman SR. Do words facilitate object categorization in 9-month-old infants? Journal of Experimental Child Psychology. 1997; 64:3–26. [PubMed: 9126625]

Baldwin DA, Markman EM. Establishing word-object relations: A first step. Child Development. 1989; 60:381–398. [PubMed: 2924658]

Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: Conceptual, strategic and statistical considerations. Journal of Personality and Social Psychology. 1986; 51:1173–1182. [PubMed: 3806354]

Bates, E.; Bretherton, I.; Snyder, L. From first words to grammar: Individual differences and dissociable mechanisms. Cambridge University Press; Cambridge, UK: 1988.

Bloom, L. Language development from two to three. Cambridge University Press; Cambridge, UK: 1993.

Bornstein MH, Haynes MO, Painter KM. Sources of child vocabulary competence: A multivariate model. Journal of Child Language. 1998; 25:367–393. [PubMed: 9770912]

Bowerman, M. Learning how to structure space for language – A crosslinguistic perspective. In: Bloom, P.; Peterson, M.; Nadel, L.; Garrett, M., editors. Language and space. The MIT Press; Cambridge, MA: 1996. p. 385-436.

Bowerman, M.; Choi, S. Space under construction: Language-specific spatial categorization in first language acquisition. In: Gentner, D.; Goldin-Meadow, S., editors. Language in Mind: Advances in the study of language and thought. MIT Press; Cambridge, MA: 2003. p. 387-427.

Bowerman, M.; Levinson, SC., editors. Language acquisition and conceptual development. Cambridge University Press; Cambridge, UK: 2001.

Cannon, J.; Levine, S.; Huttenlocher, J. A system for analyzing children and caregivers' language about space in structured and unstructured contexts. Spatial Intelligence and Learning Center; 2007.

Cartmill, E.; Pruden, SM.; Levine, SC.; Goldin-Meadow, S. The role of parent gesture in children's spatial language development. In: Franich, K.; Iserman, KM.; Keil, LL., editors. Proceedings of the 34th Annual Boston University Conference on Language Development; Somerville, MA. Cascadilla Press; 2010.

Casasola M. Can language do the driving? The effect of linguistic input on infants' categorization of support spatial relations. Developmental Psychology. 2005; 41:183–192. [PubMed: 15656748]

Casasola M, Bhagwat J, Burke AS. Learning to form a spatial category of tight-fit relations: How experience with a label can give a boost. Developmental Psychology. 2009; 45:711–723. [PubMed: 19413427]

Childers JS, Durham TW, Wilson S. Relation of performance on the Kaufman Brief Intelligence Test with the Peabody Picture Vocabulary Test – Revised among preschool children. Perceptual and Motor Skills. 1994; 79:1195–1199. [PubMed: 7899004]

Choi S, Bowerman M. Learning to express motion events in English and Korean: The influence of language-specific lexicalization patterns. Cognition. 1991; 41:83–121. [PubMed: 1790656]

Clark, EV. First language acquisition. Cambridge University Press; Cambridge, UK: 2003.

Dessalegn B, Landau B. More than meets the eye: The role of language inbinding and maintaining feature conjunctions. Psychological Science. 2008; 19:189–195. [PubMed: 18271868]

Dunn, LM.; Dunn, LM. Peabody Picture Vocabulary Test. 3rd ed. American Guidance Service; Circle Pines, MN: 1997.

Evans MA, Shaw D. Home grown for reading: Parental contributions to young children's emergent literacy and word recognition. Canadian Psychology. 2008; 49:89–95.

Fenson L, Dale PS, Reznick JS, Bates E, Thal DJ, Pethick SJ, Tomasello M, Mervis CB, Stiles J. Variability in early communicative development. Monographs of the Society for Research in Child Development. 1994; 59:1–185. [PubMed: 7845413]

Gentner D. Metaphor as structure mapping: The relational shift. Child Development. 1988; 59:47–59.

Gentner, D. Why we're so smart. In: Gentner, D.; Goldin-Meadow, S., editors. Language in mind: Advances in the study of language and thought. The MIT Press; Cambridge, MA: 2003. p. 195-235.

Gentner, D.; Goldin-Meadow, S. Language in mind: Advances in the study of language and thought. The MIT Press; Cambridge, MA: 2003.

Gentner, D.; Loewenstein, J. Relational language and relational thought. In: Amsel, E.; Byrnes, JP., editors. Language, literacy, and cognitive development: The development of consequences of symbolic communication. Lawrence Erlbaum Associates; Mahwah, NJ: 2002. p. 87-120.

Gentner, D.; Ratterman, MJ. Language and the career of similarity. In: Gelman, SA.; Byrnes, JP., editors. Perspectives on thought and language: Interrelations in development. Cambridge University Press; London: 1991. p. 225-277.

Gentner, D.; Simms, N.; Flusberg, S. Relational language helps children reason analogically. In: Taatgen, NA.; van Rign, H., editors. Proceedings of the 31st Annual Conference of the Cognitive Science Society; Austin, TX. Cognitive Science Society; 2009. p. 1054-1059.

Gumperz, JJ.; Levinson, SC., editors. Rethinking linguistic relativity. Cambridge University Press; New York, NY: 1996.

Haden CA, Ornstein PA. Research on talking about the past: The past, present, and future. Journal of Cognition and Development. 2009; 10:135–142.

Harris PL, de Rosnay M, Pons F. Language and children's understanding of mental states. Current Directions in Psychological Science. 2005; 14:69–73.

Hart, B.; Risley, TR. Meaningful differences in the everyday experience of young American children. Brookes Publishing; Baltimore, MD: 1995.

Hermer-Vasquez L, Moffet A, Munkholm P. Language, space, and the development of cognitive flexibility in humans: The case of two spatial memory tasks. Cognition. 2001; 79:263–299. [PubMed: 11165214]

Hoff E, Naigles L. How children use input to acquire a lexicon. Child Development. 2002; 73:418–433. [PubMed: 11949900]

Hoff-Ginsberg E. The relation of birth order and socioeconomic status to children's language experience and language development. Applied Psycholinguistics. 1998; 19:603–629.

Hoffman JE, Landau B, Pagani B. Spatial breakdown in spatial construction: Evidence from eye fixations in children with Williams syndrome. Cognitive Psychology. 2003; 46:260–301. [PubMed: 12694695]

Humphreys LG, Lubinski D, Yao G. Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientists, or artist. Journal of Applied Psychology. 1993; 78:250–261. [PubMed: 8482696]

Huttenlocher J, Haight W, Bryk A, Seltzer M, Lyons T. Early vocabulary growth: Relation to language input and gender. Developmental Psychology. 1991; 27:236–248.

Huttenlocher, J.; Levine, SC. Primary Test of Cognitive Skills. CTB/McGraw-Hill; Monterey, CA: 1990.

Huttenlocher J, Vasilyeva M, Cymerman E, Levine SC. Language input at home and at school: Relation to syntax. Cognitive Psychology. 2002; 45:337–374. [PubMed: 12480478]

Huttenlocher J, Vasilyeva M, Waterfall HR, Vevea J, Hedges LV. The varieties of speech to young children. Developmental Psychology. 2007; 43:1062–1083. [PubMed: 17723036]

Iacobucci, D. Mediation analysis. Sage Publications; Thousand Oaks, CA: 2008.

Internicola RW, Weist R. The acquisition of simple and complex spatial locatives in English: A longitudinal investigation. First Language. 2003; 23:239–248.

Kotovsky L, Gentner D. Comparison and categorization in the development of relational similarity. Child Development. 1996; 67:2797–2822.

Levine SC, Huttenlocher J, Taylor A, Langrock A. Early sex differences in spatial skill. Developmental Psychology. 1999; 35:940–949. [PubMed: 10442863]

Levine, SC.; Ratliff, KR.; Huttenlocher, J.; Cannon, J. Early puzzle play: Apredictor of preschoolers' mental transformation skill. 2011. Manuscript currently under review

Levine SC, Suriyakham LW, Huttenlocher J, Rowe ML, Gunderson EA. What counts in the development of young children's number knowledge? Developmental Psychology. 2011; 47:1309–1319.

Loewenstein J, Gentner D. Relational language and the development of relational mapping. Cognitive Psychology. 2005; 50:315–353. [PubMed: 15893523]

Lohmann H, Tomasello M. The role of language in the development of false belief understanding: A training study. Child Development. 2003; 74:1130–1144. [PubMed: 12938709]

Meins E, Fernyhough C, Wainwright R, Gupta MD, Fradley E, Tuckey M. Maternal mind-mindedness and attachment security as predictors of theory of mind understanding. Child Development. 2002; 73:1715–1726. [PubMed: 12487489]

Naigles LR, Hoff E, Vear D. Flexibility in early verb use: Evidence from a multiple-n diary study. Monographs of the Society for Research in Child Development. 2009; 74

Naigles LR, Hoff-Ginsberg E. Why are some verbs learned before other verbs? Effects of input frequency and structure on children's early verb use. Journal of Child Language. 1998; 25:95–120. [PubMed: 9604570]

Pan BA, Rowe ML, Singer JD, Snow CE. Maternal correlates of growth in toddler vocabulary production in low-income families. Child Development. 2005; 76:763–782. [PubMed: 16026495]

Pederson E, Danziger E, Wilkins D, Levinson S, Kita S, Senft G. Semantic typology and spatial conceptualization. Language. 1998; 74:557–589.

Preacher KJ, Hayes AF. SPSS and SAS procedures for estimating indirect effects in simple mediation models. Behavior Research Methods, Instruments and Computers. 2004; 36:717–731.

Pruden, SM.; Levine, SC. Factors affecting spatial language development: Are there sex differences?. Poster presented at the biennial meeting for the Society for Research in Child Development; Montreal, Canada. Apr. 2011

Pyers JE, Senghas A. Language promotes false-belief understanding: Evidence from learners of a new sign language. Psychological Science. 2009; 20:805–812. [PubMed: 19515119]

Pyers JE, Shusterman A, Senghas A, Spelke ES, Emmorey K. Evidence from an emerging sign language reveals that language supports spatial cognition. Proceedings of the National Academy of Sciences. 2010; 107:12116–12120.

Rattermann, MJ.; Gentner, D. The effect of language on similarity: The use of relational labels improves young children's performance in a mapping task. In: Holyoak, K.; Gentner, D.; Kokinov, B., editors. Advances in analogy research: Integration of theory and data from the cognitive, computational, and neural sciences. New Bulgarian University; Sophia: 1998. p. 274-282.

Rattermann, MJ.; Gentner, D.; DeLoache, J. The effects of familiar labels on young children's performance in an analogical mapping task. Proceedings of the Twelfth Annual Conference of the Cognitive Science Society; Hillsdale, NJ. Lawrence Erlbaum Associates; 1990. p. 22-29.

Rowe ML. Child-directed speech: Relation to socioeconomic status, knowledgeof child development and child vocabulary skill. Journal of Child Language. 2008; 35:185–205. [PubMed: 18300434]

Shea DL, Lubinski D, Benbow CP. Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study. Journal of Educational Psychology. 2001; 93:604–614.

Shusterman, A. Unpublished doctoral dissertation. 2006. Interactions between language and thought in spatial cognitive development.

Stieff M. Mental rotation and diagrammatic reasoning in science. Learning and Instruction. 2007; 17:219–234.

Szechter LE, Liben LS. Parental guidance in preschoolers' understanding of spatial-graphic representations. Child Development. 2004; 75:869–885. [PubMed: 15144491]

Talmy, L. Lexicalization patterns: Semantic structure in lexical forms. In: Shopen, T., editor. Language typology and the lexicon. Vol. Vol. III: Grammatical categories and the lexicon. Cambridge University Press; Cambridge, UK: 1985. p. 57-149.

Taumoepeau M, Ruffman T. Mother and infant talk about maternal states relates to desire language and emotion understanding. Child Development. 2006; 77:465–481. [PubMed: 16611184]

Wai J, Lubinksi D, Benbow CP. Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. Journal of Educational Psychology. 2009; 101:817–835.

Wechsler, D. Wechsler Preschool and Primary Scale of Intelligence. Third Edition (WPPSI-III). Pearson/PsychCorp; San Antonio, TX: 2002.

Weizman ZO, Snow CE. Lexical output as related to children's vocabulary acquisition: Effects of sophisticated exposure and support for meaning. Developmental Psychology. 2001; 37:265–279. [PubMed: 11269394]

Whorf, B. Language, thought and reality. MIT Press; Cambridge, MA: 1956.

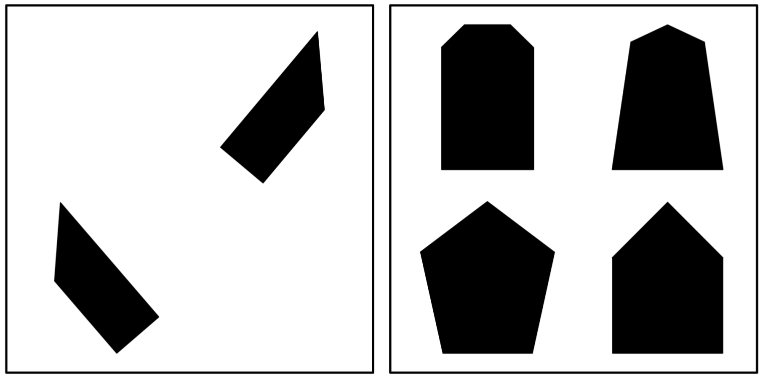

Figure 1.
Sample item from the Spatial Transformation task (Levine et al., 1999). While viewing the figures children were asked to select a shape that the two pieces would make if they were put together.

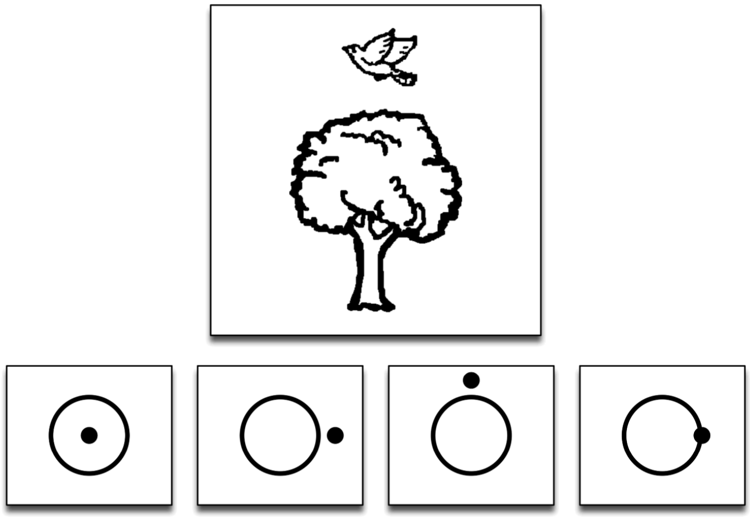

Figure 2.
Sample item from the Spatial Analogies test (adapted from the PTCS; Huttenlocher & Levine, 1990). Children were asked to select one picture out of the four that "goes best" with the target picture. Picture reprinted with permission of The McGraw-Hill Companies, Inc.

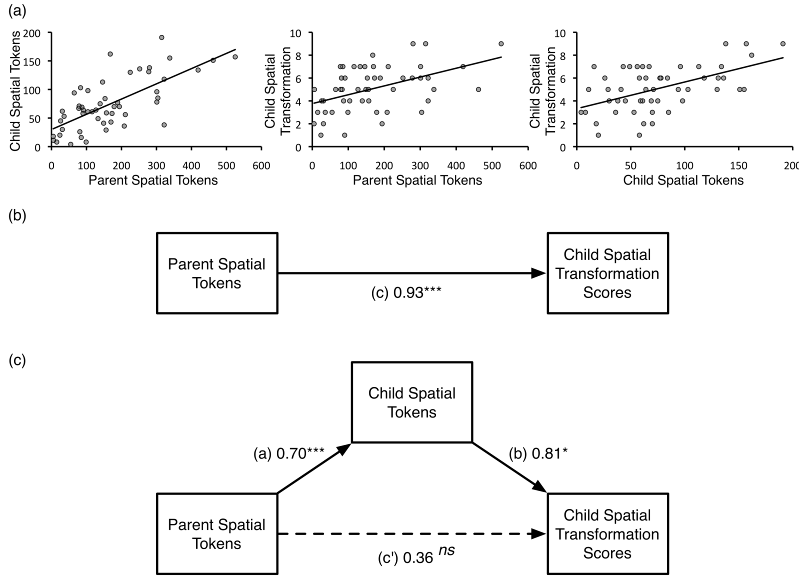

Figure 3.

Scatter plots (3a) showing: (1) the relation between parent's spatial tokens by 46 months and children's spatial tokens by 46 months (top left; $r = 0.55$, $p \leq .001$), (2) the relation between parent's spatial tokens by 46 months and children's scores on the Spatial Transformation task (top middle; $r = 0.27$, $p \leq .05$) and (3) the relation between children's spatial tokens by 46 months and children's scores on the Spatial Transformation task (top right; $r = 0.39$, $p \leq .01$), after controlling for parent's other tokens and children's other tokens. The mediation analysis reveals that the direct effect (*c*) of parent spatial tokens on children's spatial transformation scores (3b) is no longer significant when children's spatial tokens are included as a potential mediator (3c; *c*'). These results suggest that children's own production of spatial language accounts for the relation between parent spatial language and children's spatial transformation scores. ($n = 52$, β = Standardized regression coefficient, $^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$).

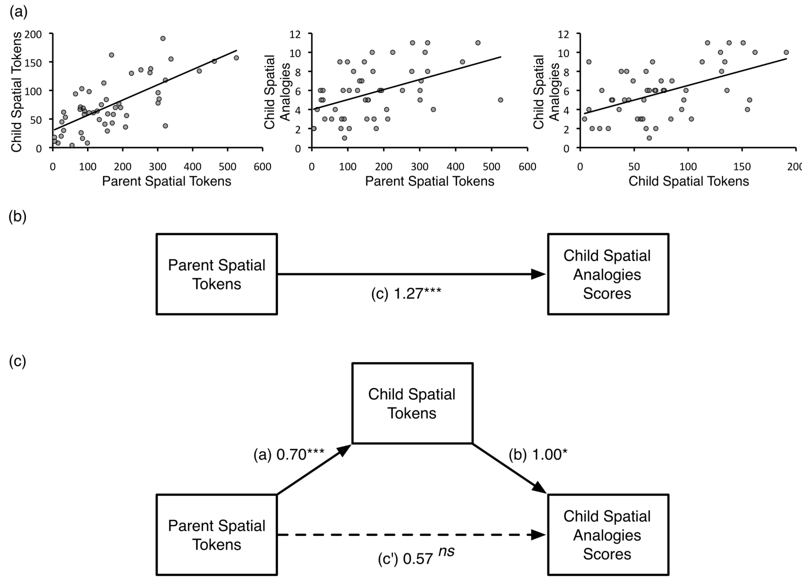

Figure 4.

Scatter plots (4a) showing: (1) the relation between parent's spatial tokens by 46 months and children's spatial tokens by 46 months (top left; $r = 0.55$, $p \le .001$), (2) the relation between parent's spatial tokens by 46 months and children's scores on the Spatial Analogies test (top middle; $r = 0.30$, $p \le .05$) and (3) the relation between children's spatial tokens by 46 months and children's scores on the Spatial Analogies test (top right; $r = 0.39$, $p \le .01$), after controlling for parent's other tokens and children's other tokens. The mediation analysis reveals that the direct effect (*c*) of parent spatial tokens on children's spatial analogies scores (4b) is no longer significant when children's spatial tokens are included as a potential mediator (4c; *c*'). These results suggest that children's own production of spatial language accounts for the relation between parent spatial language and children's spatial analogies scores. ($n = 50$, β = Standardized regression coefficient, $^{*}p \le .05$, $^{**}p \le .01$, $^{***}p \le .001$).

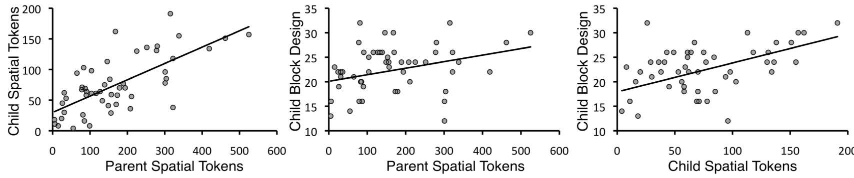

Figure 5.

Scatter plots showing (1) the relation between parent's spatial tokens by 46 months and children's spatial tokens by 46 months (top left; $r = 0.55$, $p \leq .001$), (2) the relation between parent's spatial tokens by 46 months and children's scores on the WPPSI-III Block Design subtest (top middle; $r = 0.09$, $p > .05$) and (3) the relation between children's spatial tokens by 46 months and children's scores on the WPPSI-III Block Design subtest (top right; $r = 0.33$, $p \leq .05$), after controlling for parent's other tokens and children's other tokens. The relation between parent's spatial tokens and children's scores on the WPPSI-III Block Design subtest was no longer significant, so we did not conduct mediation analyses as this was no longer an appropriate test. ($n = 51$, $^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$).

Table 1

Demographic Information

		Education					
		Less than high school education	**High-school degree or GED**	**Some College**	**College Degree**	**Advanced Degree**	**Total**
Income	Less than $15,000	1	1	1	0	0	3
	$15,000-$34,999	1	2	3	0	1	7
	$35,000-$49,999	0	0	3	2	2	7
	$50,000-$74,999	0	0	0	7	3	10
	$75,000-$99,999	0	2	1	6	3	12
	$100,000 or more	0	1	1	4	7	13
	Total	2	6	9	19	16	52

Note. Income and education of the families can change over the course of the longitudinal project. These data reflect information of the families from their last visit (54 months).

Table 2

Descriptive Statistics for Language Production by 46 Months

	M	SD	Minimum	Maximum
Children's Language				
Other Tokens[1]	11372.15	4355.47	3859	22310
Other Types[1]	765.31	204.12	387	1213
Spatial Tokens	74.44	45.71	4	191
Spatial Types	11.06	5.27	1	22
Parent's Language				
Other Tokens[1]	30257.38	14466.06	6009	71926
Other Types[1]	1326.90	360.39	566	2103
Spatial Tokens	167.06	120.52	5	525
Spatial Types	19.77	8.47	2	42

[1]*Note*. Other tokens and other types included all other words besides spatial tokens and types.

Table 3

Most Common Spatial Terms

	% Parent Produced	% Child Produced
Shape Terms		
Circle	80%	72%
Shape	72%	30%
Square	65%	43%
Triangle	62%	45%
Dimension Terms		
Little	100%	88%
Big	98%	100%
Small	87%	52%
Long	78%	57%
Tall	72%	38%
Full	72%	27%
Tiny	50%	27%
Empty	50%	22%
Spatial Feature Terms		
Side	68%	23%
Line	60%	45%
End	58%	25%

Note. This table represents only a sample of spatial words said by parents and their children. Only those terms that were produced by at least 50% of parents are reported in this table. However, all spatial terms, even those produced by fewer than 50% of parents are included in further statistical analyses.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Table 4

Descriptive Statistics for Non-Verbal Spatial Tasks Administered at 54 Months

	M	SD	Minimum	Maximum	N
Spatial Transformation Task	5.06	1.97	1	9	52
Block Design Subtest	22.76	4.72	12	32	51
Spatial Analogies	5.78	2.74	1	11	50

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 5

Correlations between parent and child spatial tokens, other tokens and performance on three non-verbal spatial tasks

Measure	1	2	3	4	5	6	7
1. Child Other Tokens[1]	–	.57***	.36**	.39**	.30*	.26	.26
2. Child Spatial Tokens		–	.54***	.70***	.54***	.45***	.52***
3. Parent Other Tokens[1]			–	.86***	.39**	.27	.37**
4. Parent Spatial Tokens				–	.48***	.29*	.47***
5. Spatial Transformation Task					–	.49***	.39**
6. Block Design Subtest						–	.47***
7. Spatial Analogies							–

[1] *Note*. Other tokens included all other words besides spatial tokens.

* $p \leq .05$,

** $p \leq .01$,

*** $p \leq .001$.

Table 6

Predictors of Children's Block Design Scores at 54 months

Predictors	Model 1	Model 2	Model 3	Model 4
	β	β	β	β
Parent's Other Tokens[1]	0.27*	0.09	0.07	0.22
Parent's Spatial Tokens		0.22	0.17	−0.25
Children's Other Tokens[1]			0.17	−0.02
Children's Spatial Tokens				0.52*
R^2 (adj.)	5.5%	4.9%	5.6%	14.5%

[1] *Note*. Other tokens included all other words besides spatial tokens. *β* = Standardized regression coefficient;

* $p \leq .05$,

** $p \leq .01$,

*** $p \leq .001$.