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Three-Year-Olds' Spatial Language Comprehension and Links With Mathematics and Spatial Performance

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Early spatial skills predict the development of later spatial and mathematical skills. Yet, it is unclear how comprehension of the words that capture spatial relations, words like *behind* and *under*, might be associated with children's early spatial and mathematics skills. The current study addressed this question by conducting a moderated mediation model to test the potential moderating effects of group factors, such as socioeconomic status (SES) and gender, on the possible mediation of spatial language comprehension on the association between spatial skill and mathematics performance. In total, 192 3-year-olds were tested on a battery of assessments, including a novel Spatial Language Comprehension Task, a test of spatial skills (2- and 3-dimensional trials of the Test of Spatial Assembly [2D and 3D TOSA, respectively]), and a composite of 2 mathematical assessments. The results indicate that this novel Spatial Language Comprehension Task is a reliable measure useful for examining group differences and the early space–math link. Specifically, higher-SES preschoolers and females had higher spatial language comprehension compared with their lower-SES peers and males, respectively. These SES and gender disparities in spatial language comprehension are concerning, given the strong association between spatial language comprehension and mathematics skills. Additionally, spatial language comprehension mediated the association between spatial skill and mathematics performance for females only. Future work should examine the potential causal role that spatial language comprehension may have in concurrent and later spatial and mathematics skills.

Keywords: spatial language, spatial development, mathematics, preschool

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Spatial skills are what we use to mentally and physically manipulate the location and orientation of our environment and the things in it. As such, they are essential for everyday functioning. Navigating to the supermarket, putting together a piece of unassembled furniture, and positioning a credit card in an ATM all require spatial skills. Fields ranging from architecture to medicine depend on them; they help engineers imagine a weight-bearing structure and scientists interpret diagrams. The study of children's spatial skills is an important topic in its own right, and interest in the area has been increasing, especially as research increasingly suggests that spatial skills have strong links to early mathematics (e.g., Cheng & Mix, 2014; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2017) and future science, technology, engineering, and math (STEM) achievement (e.g., Wai, Lubinski, & Benbow, 2009). Understanding the development of these skills in early childhood and their underlying components is critical to promoting

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school readiness and adequately preparing children for a STEM-centric world. The current study examined one of these critical components, spatial language, and its early association with children's spatial and mathematics skills.

Spatial language consists of words and phrases used to describe spatial relations between objects (such as *over* or *on top of*), as well as properties of objects (e.g., *circle*, *tall*, *small*). Spatial language appears to play an important role in children's development of spatial skills. One study found that parents who engaged their 5-year-old children in spatial talk during book reading had children who performed better on spatial comprehension tasks (Szechter & Liben, 2004). Another study found that 4-year-olds' own production of spatial language while interacting with their parent at a children's museum block-wall exhibit predicted their performance on a spatial task (Polinsky, Perez, Grehl, & McCrink, 2017). Thus, children's reception and production of spatial language are associated with spatial skill development.

Development of Spatial Language

The acquisition of spatial language rests on developments in infancy. Infants start to develop basic representations and categories for spatial terms between 3 and 10 months of age (Casasola, Cohen, & Chiarello, 2003; Quinn, 1994; Quinn, Adams, Kennedy, Shettler, & Wasnik, 2003) and may have "core" prelinguistic spatial concepts (Landau, 2020). However, children generally begin to produce and comprehend simple spatial prepositions (e.g., *in*, *on,* and *under*) around 2 years of age (Brown, 1973; Clark, 2004; Fenson et al., 1994; Johnston & Slobin, 1979; Meints, Plunkett, Harris, & Dimmock, 2002; Weist, Lymburner, Piotrowski, & Stoddard, 2000) and more complex prepositions, such as those that require more than two objects or multiple axes of representation (i.e., *front*, *behind*, and *between*) at about 5 years of age (Brown, 1973; Foster & Hund, 2012; Johnston, 1984; Johnston & Slobin, 1979; Washington & Naremore, 1978; Weist et al., 2000). Pruden, Levine, and Huttenlocher (2011) found that parents' use of spatial language about properties of objects when children were 1 to 3 years of age correlated with their children's performance on a number of spatial tasks at 4.5 years of age. That is, children who used and heard more language describing the size, shape, and properties of objects (e.g., *tall, circle*) scored higher on later spatial skill assessments. However, this study did not ask whether describing *where* an object is located in space (i.e., location terms such as *near*, *up*, and *under*) would elicit the same outcomes.

Spatial Language and Spatial Skills

The use of and exposure to location terms may also relate to children's spatial skills development. For example, Balcomb, Newcombe, and Ferrara (2011) found that the number of location terms or prepositions (e.g., *on, inside, up*) 16- to 24-month-olds use was significantly and positively correlated to their performance on a place-learning spatial task in which they were asked to locate a hidden target item. Whether there is a causal link between spatial language and task performance is unclear. However, several other studies have shown that children exposed to relevant spatial language describing the location of an object show improved performance on a spatial task involving that object (Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Miller, Patterson, & Simmering, 2016). During a spatial mapping task, for example, an experimenter used spatial relational language (e.g., "I'm putting this *on* the box") while placing a card in one of three locations (e.g., *on* top of the box) in the "Hiding" box. The child then needed to find the card in the corresponding location in a different box, the "Finding" box. Hearing this spatial relational language boosted 4-year-olds' performance in finding a card in the corresponding location of the Finding box compared with children who heard nonrelational language (e.g., "I'm putting this *here*"). However, the same spatial relational language did not benefit 3-year-olds (Loewenstein & Gentner, 2005). Why might spatial relational terms be difficult to learn and use, especially for younger children? One reason is that an object's location in space can be described in multiple ways—for instance, an object can simultaneously be *under* the cup and *on* the table—adding to the complexity of parsing the meaning of these words in everyday speech. Furthermore, whether an object is *behind* or *in front of* another object depends on the speaker's position vis-à-vis the object. Because the speaker's position is not always the same as the child's position, this requires the child to engage in perspective taking, a late-developing skill (e.g., Newcombe, 1989).

Spatial Language and Mathematics Skills

Some work has extended this relation between spatial language comprehension and spatial skills to mathematical skills. The relation between early mathematical skills and the comprehension of quantifiers (e.g., *all, some, none*), or what Cannon, Levine, and Huttenlocher (2007) call the "continuous amount" spatial category, relates to 2-year-olds' ability to acquire certain early mathematical skills (Barner, Chow, & Yang, 2009). Spatial language produced by children during block play may be important for later mathematical skills. For example, Ramani, Zippert, Schweitzer, and Pan (2014) suggest that spatial talk between peers during block-building (e.g., "Turn the piece on its side") and mathematical talk (e.g., "Place two blocks on the bridge") could facilitate later mathematics learning. Spatial language may also provide children with the tools to talk about numbers on a number line, which research suggests is intertwined with mathematical learning (Mix & Cheng, 2012; Siegler & Booth, 2004). Purpura, Napoli, Wehrspann, and Gold (2017) took these assertions beyond correlational data to conduct an intervention study to support the connection between spatial-mathematical language and mathematics. Researchers randomly assigned preschool children to a dialogic reading intervention incorporating mathematical language, including spatial relational terms, such as *under* and *between*. At the end of the 8-week intervention, children who received the dialogic reading protocol incorporating spatial terms had significantly higher scores on a mathematics assessment than their peers who did not receive the intervention. However, it is unclear if the spatial language or the other mathematical language (or both) was the cause. Thus, no studies have examined the association between explicit spatial language comprehension and mathematics achievement in young children. The current study, however, speaks to this issue by examining the direct relation between 3-year-olds' spatial language comprehension and their mathematical skills. Additionally, no study explored the associations between spatial skill, spatial language comprehension, and mathematical skills. Might spatial language mediate the established association between spatial skill and mathematics performance? And might group factors such as socioeconomic status (SES) and gender moderate this association for children as young as 3 years of age?

Socioeconomic Status and Gender Differences

Socioeconomic Status

Many low-SES preschoolers lag behind their middle-SES peers in spatial skills (e.g., Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005; Verdine, Golinkoff, et al., 2017). Discrepancies in general language exposure and development have been well documented between children from underserved communities and their peers from more advantaged communities (e.g., Golinkoff, Hoff, Rowe, Tamis-LeMonda, & Hirsh-Pasek, 2019; Hart & Risley, 1995; Hoff, 2003; Lee & Burkam, 2002; Levine et al., 2020), with lower-SES children already lagging behind their peers in general vocabulary and language processing as early as 18 months (Fernald, Marchman, & Weisleder, 2013; Halle et al., 2009). Several studies found that children from underserved communities score significantly lower on assessments of preposition knowledge and mathematical language than their peers from more advantaged communities (Hustead, 1974; Purpura & Reid, 2016; Schutz & Keislar, 1972). Even when children understand spatial terms, children from lower-SES households are slower to process them in an eye-tracking task (Verdine, Bunger, Athanasopoulou, Golinkoff, & Hirsh-Pasek, 2017) and trail behind their higher-SES peers in spatial and mathematics performance (e.g., Bower, Zimmermann, et al., 2020; Starkey, Klein, & Wakeley, 2004; Verdine, Golinkoff, et al., 2017). Perhaps these language discrepancies may contribute to later gaps in mathematics achievement.

Gender

Previous research suggests conflicting evidence for a male advantage in spatial skills, in addition to the sources of gender differences in spatial skills, the size of those differences, and the ages at which they emerge (e.g., Frick, Möhring, & Newcombe, 2014; Lauer, Yhang, & Lourenco, 2019; Levine, Foley, Lourenco, Ehrlich, & Ratliff, 2016; Levine, Huttenlocher, Taylor, & Langrock, 1999; Liben, 2006; Linn & Petersen, 1985; Nazareth, Herrera, & Pruden, 2013; Newcombe, Bandura, & Taylor, 1983; Quinn & Liben, 2008; Uttal et al., 2013; Verdine, Golinkoff, et al., 2017). Additionally, past research into gender differences in language acquisition may also help us understand children's acquisition of spatial prepositions. A consistent slight advantage for females compared with males has been found, with females demonstrating greater lexical knowledge (Fenson et al., 1994) and faster vocabulary growth (Bauer, Goldfield, & Reznick, 2002; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991). However, gender differences are very small and account for only 1–2% of the variance (Fenson et al., 1994). Additionally, this female advantage is only evident in the initial stages of language development; gender differences generally decrease or even disappear by age 3 as males catch up to their female peers (Huttenlocher, Waterfall, Vasilyeva, Vevea, & Hedges, 2010; Le Normand, Parisse, & Cohen, 2008; Rowe, 2012; Simonsen, Kristoffersen, Bleses, Wehberg, & Jørgensen, 2014). Barbu et al. (2015) examined the interactions between SES and gender in language development and found a gender difference after age 3 for lower-SES children only, such that lower-SES males still lagged significantly behind lower-SES females in preschool.

Yet few studies have examined gender differences in spatial language per se. Casasola (2005) found no sex differences in how 18-month-olds formed an abstract spatial category of support (e.g., placing one object on another) with linguistic input. Another study by Pruden and Levine (2017) found that at 3 years of age, boys produced more spatial language about object features (e.g., *big, short, circle, curvy*) than girls, and this difference was fully mediated by the difference in spatial language parents used with boys and girls when they were 14 to 26 months old. Still, the consistent slight female advantage for vocabulary raises the question of whether this difference extends to children's comprehension of spatial prepositions.

Current Study

In the current study, a new measure of spatial language comprehension, adapted from Park and Casasola (2017), was developed. It makes minimal demands on 3-year-olds with the use of familiar objects (a teddy bear and a bucket) placed in different spatial relations. The virtue of using the same familiar objects on all trials is that the spatial relations depicted were more noticeable for children rather than the objects themselves. Furthermore, because the task required only a pointing response, young children could readily respond to requests. The goal of the current study was to examine children's early spatial language comprehension and its relation to concurrent spatial skill (i.e., performance on the two- and three-dimensional trials of the Test of Spatial Assembly [2D and 3D TOSA, respectively]; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014) and mathematical performance. Specifically, we explored the possible mediation of spatial language comprehension on the association between spatial and mathematical skills. Because the association between spatial and mathematical skills has been well documented in previous literature (e.g., Mix, 2019), spatial language comprehension may act as a tool to further develop and connect spatial skills to mathematical learning by bolstering spatial and quantitative-relational reasoning. We also examined whether spatial language comprehension varied by group factors, such as SES and gender, and whether these groups moderated the mediation of spatial language comprehension on the established association between spatial and mathematical skills.

We hypothesized that, in line with previous research, higher-SES children would perform significantly better on the spatial language assessment than their lower-SES peers. We also predicted that males would perform significantly better than females, given the male advantage often reported on the specific spatial skill of mental rotation (e.g., Levine et al., 2016) and the production of spatial language about object features (Pruden & Levine, 2017). Additionally, if spatial language is implicated in children's acquisition of spatial and mathematical skills (e.g., Pruden et al., 2011), we would expect that spatial language comprehension (a) predicts mathematics performance and, more specifically, (b) mediates the established association between spatial skill and mathematics performance with a potential moderation by gender or SES, such that the mediation would be significant for males and higher-SES children.

Method

Participants

Of the initial 206 children recruited, 9 were excluded before analyses (2 were too old; 1 was too young; 6 failed to complete the task). An additional three children were excluded for failing to correctly identify the three or four familiar objects in the spatial language assessment, causing us concern about whether these children understood the task. Two additional children were excluded as outliers; their scores on the spatial language assessment were more than 3 standard deviations (*SD*) below the mean.

The final sample included 192 3-year-olds (mean [*M*] age = 42.73 months, *SD* = 3.39). Based on parent report, the sample was 46% Caucasian, 23% Black, 9% Asian, 16% other, and 6% unreported. Of all the children, 11% were Hispanic or Latino. Children were recruited from Head Start facilities as well as private preschools in the surrounding urban areas. The sample was balanced with respect to gender (male = 90, female = 102) and SES (lower SES = 94, higher SES = 98). The project, titled "Spatial Instruction in Preschool: Identifying the Malleable Factors," was approved by the institutional review boards (IRBs) of the University of Delaware and Temple University (IRB Protocols 632397-14 and 22370, respectively). Parents returned the signed consent form with a background questionnaire that requested the primary caregiver's education level, which was used as a proxy for SES, as recommended by Hoff (2013). Children were classified as higher SES if their primary caregiver had a bachelor's degree or above. Inclusion criteria required the children to be 3 years of age, be proficient in English, and not have any apparent developmental delays.

Procedure

All children were part of a larger training study that used a pretest–training–posttest design to investigate ways to improve 3-year-olds' spatial skills. However, for the current study, only a subset of the pretest assessments was examined: Spatial Language Comprehension Task, Woodcock–Johnson-IV Applied Problems (WJ-IV AP; Schrank, McGrew, & Mather, 2014) subtest, Test of Early Mathematics Ability (3rd ed.; TEMA-3; Ginsburg & Baroody, 2003) subtest, 2D and 3D TOSA, and the Woodcock–Johnson-IV Picture Vocabulary (WJ-IV PV; Schrank et al., 2014) subtest. Children were pretested individually in a private room outside of the preschool classroom. The order of tasks was randomized before the pretest. The average length of time needed to administer this subset of assessments during the pretests was 40 min.

Materials

Spatial language comprehension. To assess children's comprehension of spatial language, they were shown a page with three photographs featuring a teddy bear and a bucket and were asked to select which photograph represented the target spatial relation (i.e., *"Point to, 'The bear is under the bucket'"*; see Part A of Figure 1). Fourteen spatial relations were assessed: *under, above, between, up, in, on, down, behind, below, middle, in front of, next to, on top of,* and *upside down*. Chance performance would yield a score of 4 or 5 (33.3% of 14 = 4.66). Half of these terms were chosen because they were directly targeted for training in the spatial training portion of the intervention study, and half were adapted from items in Park and Casasola (2017). The 14 trials were interspersed with 4 "familiar object" trials (flower, bird, shoe, and fish) that asked the child to find the object from a set of three pictures. These trials were designed to ensure children were attending to and understanding the task directions. In the current study, children who answered only one or two of these familiar items correctly were discarded from analyses. Throughout the task, experimenters were careful to modulate their voices to differentiate "Point to" and the target sentence. Children were given 1 point if they pointed to the target picture, for a possible total score of 14. If a child did not respond or pointed to multiple pictures, the experimenter repeated the prompt while moving a finger along all three images. If the child still neglected to respond, the experimenter pointed to each image discretely and asked, "Is it this one, this one, or this one?" If the child still did not respond after both follow-up prompts, the experimenter proceeded to the next item, and the item was counted as incorrect. This measure was presented within a battery of assessments as part of a pretest for the training study. The order of the appearance of this task was counterbalanced across children. On average, the task took approximately 2 min to administer. Using DeVellis's (2016) standards, the task had acceptable reliability, with a Cronbach's alpha of .75.

Spatial skills. Children's spatial ability was measured with the 2D and 3D TOSA (Verdine et al., 2014). On the 2D TOSA (see Part B of Figure 1), children used individual magnetic shapes to replicate a flat image of a model shape arrangement when given the pieces. Two training trials were administered, during which the experimenter demonstrated the task, then asked the child to "make your pieces look just like the picture." If a child failed to re-create the image successfully on the first try, the experimenter corrected the child and asked the child to try again. If the child still failed to replicate the image successfully, the experimenter corrected the puzzle and moved on to the next training puzzle. After the training trials, six testing trials were administered in order of increasing complexity, as indicated by the number of component pieces. Each of the six testing trials was then coded for accuracy based on three dimensions (e.g., correct adjacent pieces, correct horizontal and vertical placement of pieces, and correct relative position of pieces). The mean of the correct dimensions was used as the 2D TOSA score (see Verdine, Golinkoff, et al., 2017 for more details on coding). On the 3D TOSA (see Part C of Figure 1), children used individual Lego Duplo interlocking blocks to re-create a model to the best of their ability. Two training trials were again administered, during which the experimenter provided the same modeling, feedback, and corrections as in the 2D trials. After the training trials, eight testing trials were administered, again with increasing complexity, as indicated by the number of component blocks. Each of the eight testing trials was then coded for accuracy based on three dimensions (e.g., correct vertical location of blocks, correct rotation of blocks, and placement of blocks over correct block pips). The total number of correct dimensions was used as the 3D TOSA score (see Verdine, Golinkoff, et al., 2017 for more details on coding). *Z* scores were created for both the 2D and 3D TOSA and composited for a general spatial skill score.

Mathematics. The WJ-IV AP (Schrank et al., 2014) subtest and the TEMA-3 (Ginsburg & Baroody, 2003) were given to

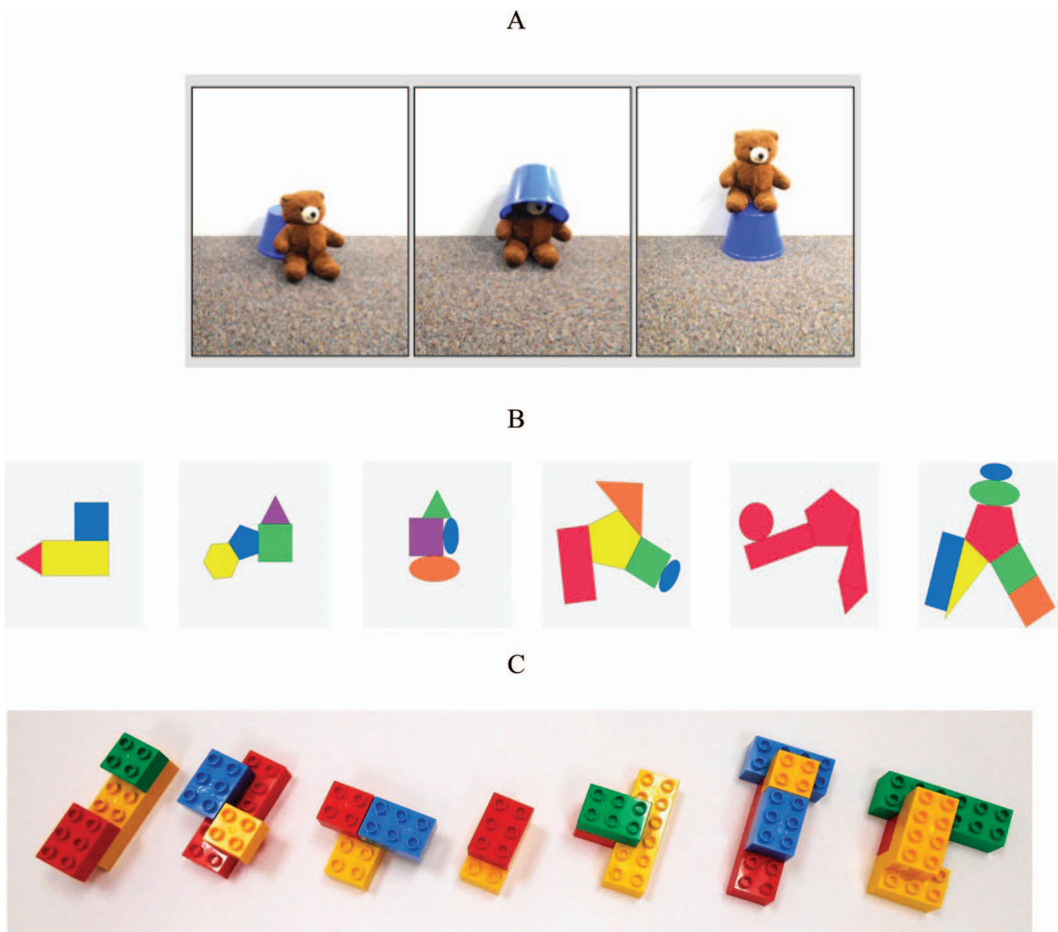

Figure 1. A. Sample item from the Spatial Language Comprehension Task ("Point to 'The bear is *under* the bucket'"). B. Sample items from the two-dimensional trials of the Test of Spatial Assembly (2D TOSA; Bower et al., 2020). C. Sample items from the three-dimensional trials of the TOSA (3D TOSA; Bower et al., 2020). See the online article for the color version of this figure.

children. In the WJ-IV AP subtest, children were shown an image and asked a question relating to early skills in mathematics (i.e., "There are five children. There are three balloons. How many children do *not* have balloons?"). Children were given 1 point for each correct response, and the assessment was discontinued after children failed to answer five consecutive items correctly, in accordance with standardized administration. Children's math skills were also assessed with a subset of the TEMA-3 because of testing time constraints. Items were selected for the subtest that assessed a variety of mathematics skills, including subitizing (4 items), number constancy (3 items), numeracy (8 items), magnitude comparison (10 items), and basic addition and subtraction with tokens (5 items). Children's correct responses received 1 point for each of the 30 items (total possible = 30). *Z* scores were created for each of the mathematics assessments and composited for a general mathematics score.

Expressive vocabulary. Children's expressive vocabulary was measured using the WJ-IV PV (Schrank et al., 2014) subtest. Children were shown an image and asked, "What is this?" Children were given 1 point for each correct response, and the assessment was discontinued after children failed to correctly identify six consecutive objects, in accordance with standardized administration.

Results

The results are organized into three sections: (a) descriptive information on the Spatial Language Comprehension Task from the sample at large, including gender and SES group differences; (b) the relation between spatial language comprehension, spatial skill, and mathematics performance; and (c) an exploratory moderated mediation of the effects of gender and SES on spatial language comprehension mediating the effect between spatial skill and mathematics performance. The latter two analyses involved a multiple regression and moderated mediation while controlling for expressive vocabulary performance and age in months. See Table 1 for partial correlations between child gender, SES, spatial skill (composite of 2D and 3D TOSA), spatial language comprehension, and mathematics performance (composite of TEMA-3 and WJ-AP subtests) while controlling for children's expressive vo-

Table 1
Partial Correlations of Child Gender, SES, Spatial Language Comprehension, Spatial Skill, and Mathematics Performance While Controlling for Children's Expressive Vocabulary and Age in Months

Variable	Gender	SES	Spatial language	Spatial skill	Mathematics
Gender					
SES	.03				
Spatial language	−.14*	.24***			
Spatial skill	−.08	.28****	.32****		
Mathematics	−.14*	.39****	.53****	.52****	

Note. SES = socioeconomic status. For gender, females were coded as 0 and males as 1. For SES, low SES was coded as 0 and high SES as 1. Spatial skill is a composite of performance on the two- and three-dimensional trials of the Test of Spatial Assembly (2D and 3D TOSA, respectively). Mathematics is a composite of performance on the Test of Early Mathematics Ability (3rd ed.; TEMA-3) and Woodcock–Johnson-IV Applied Problems (WJ-AP) subtest.
* $p < .10$. *** $p < .01$. **** $p < .001$.

cabulary and age in months. See Supplemental Table S1 in the online supplemental material for descriptive information on each measure split by gender and SES and the results of multivariate analyses of covariance (MANCOVAs) comparing gender and SES group differences on each of these measures while controlling for children's expressive vocabulary and age in months.

Spatial Language Comprehension Task—Descriptive Information

The mean number of items correctly identified was 9.41 (SD = 2.67), out of a total possible score of 14 (see Table 2 for group-level descriptive statistics). For histograms of all children's performance and performance split by child gender and SES, see Supplemental Figure S1 in the online supplemental material. For histograms of the percentage correct on each item split by child gender and SES, see Supplemental Figure S2 in the online supplemental material. For the group, this average is significantly above a chance score, which would average 4.66. Fourteen of 192 children scored around or below chance (5 or less). The most common items that children correctly identified were *in* (93.2%), *upside down* (91.1%), *up* (85.4%), and *under* (84.9%; see Supplemental Figure S2 in the online supplemental material). Children had the most difficulty with the three items that involved more than two objects or multiple axes of representation: *between* (44.3%), *behind* (38.5%), and *in front* (55.2%). Only 35 children (18.2%) responded correctly to all three of these complex spatial relations. The odds of a child getting any three items correct by chance alone is only 3.7% ($.3333^3$). Therefore, children who managed to do this are likely revealing their understanding of the vocabulary needed for describing complex spatial relations. For a breakdown of accuracy on these three complex items by child gender and SES, see Table 3.

Table 2
Group Descriptive Information of Spatial Language Comprehension Score

Statistic	Value
Mean	9.41
Standard deviation	2.67
25th percentile	7.00
50th percentile	9.00
75th percentile	11.00

Table 3
Frequency Counts of Accuracy on the Three Items That Included More Than Two Objects or Multiple Axes of Representation by Child Gender and SES

	Gender		
SES group	Male	Female	Total
Lower SES	3 (8%)	8 (23%)	11 (31%)
Higher SES	9 (26%)	15 (43%)	24 (69%)
Total	12 (34%)	23 (66%)	35

Note. SES = socioeconomic status. Percentages are out of the total 35 children who correctly identified all three complex relational items.

A 2 × 2 analysis of covariance (ANCOVA) was conducted to examine gender and SES group differences (and their interaction) on Spatial Language Comprehension Task performance while controlling for expressive vocabulary and age in months. There were significant gender, $F(1, 186) = 5.11$, $p = .025$, partial $\eta^2 = .03$, and SES differences, $F(1, 186) = 10.36$, $p = .002$, partial $\eta^2 = .05$. Females performed better than males, and high-SES children performed better than low-SES children (see Table 4 for means and standard deviations). The Gender × SES interaction was not significant, $p = .493$.

Spatial Language and Spatial Skill Predict Mathematics Performance

A multiple regression was conducted to examine the main effects of spatial language comprehension and spatial skill as well as gender and SES on mathematics performance while controlling for expressive vocabulary and age in months. The variable of spatial language comprehension was centered, and interaction terms were computed using the centered variable. Because there were significant SES and gender differences in spatial language comprehension (as described in the prior section), two 2-way interactions were also included to examine the possible interactions of spatial language comprehension with gender and SES on

Table 4
Means (SD) of Spatial Language Comprehension Score by Child Gender and SES

	Gender		
SES group	Male	Female	SES group means
Lower SES	7.83 (2.32)	9.00 (2.56)	8.48 (2.51)
Higher SES	9.98 (2.65)	10.60 (2.39)	10.30 (2.52)
Gender group means	8.98 (2.71)	9.78 (2.59)	9.41 (2.67)

Note. SES = socioeconomic status. The maximum score on the Spatial Language Comprehension Task is 14.

mathematics performance. A third 2-way interaction was included to examine the possible interaction between spatial skill and spatial language comprehension. Two 3-way interactions were initially included to examine the possible interaction between spatial language comprehension, spatial skill, and gender or SES on mathematics performance. However, because the 3-way interactions were not significant in this full model, they were removed. The reported model includes only main effects and 2-way interactions. To check for multicollinearity, the variance inflation factor (VIF) values of all main effects and interaction terms were inspected: All values were less than 4.03, indicating no significant multicollinearity.

The overall model was significant, $F(9, 172) = 31.57$, $p < .001$, $R^2 = .62$ (see Supplemental Table S2 in the online supplemental material for a summary of regression results). Both spatial language comprehension ($\beta = 0.43$, $p < .001$) and spatial skill ($\beta = 0.30$, $p < .001$) had significant main effects on mathematics performance. Of the participant variables, SES had a significant main effect on mathematics ($\beta = 0.21$, $p < .001$), but gender did not ($p = .415$). Of the 2-way interactions, only the Spatial Language Comprehension × Spatial Skill interaction was significant ($\beta = 0.13$, $p = .011$).

Because there was a significant Spatial Language Comprehension × Spatial Skill interaction and previous research supports an association between spatial skill and mathematics performance (e.g., Mix, 2019), an exploratory moderated mediation was conducted to examine the possible mediation effect of spatial language comprehension on the association between spatial skill and mathematics performance.

Exploratory Moderated Mediation

A moderated mediation is generally used to examine the influence of a variable (moderator) on the mediated relationship between the predictor and outcome (for an overview of this analysis, see Hayes, 2015; Preacher, Rucker, & Hayes, 2007). Thus, a moderated mediation was conducted in the current study to examine the possible moderation of SES and/or gender on the mediated effect of spatial language comprehension on the association between spatial skill and mathematics performance. The moderated mediation effects were estimated using the PROCESS MACRO (Hayes, 2017) and 5,000 bootstrap draws to obtain confidence intervals for the indirect effect. The moderation hypothesis—that gender and/or SES would moderate the relation between spatial skill and spatial language comprehension—was tested by incorporating both the Gender × Spatial Skill and SES × Spatial Skill interaction terms in the model. The moderated mediation hypothesis was examined by estimating the Gender × Spatial Skill and SES × Spatial Skill interactions predicting mathematics performance via spatial language comprehension (indirect effect). The results of this overall model indicate a significant moderation effect for gender only, not SES. Thus, the final moderated mediation analysis excluded SES as a moderator and examined (a) the moderation of gender on the relation between spatial skill and spatial language comprehension and (b) the Gender × Spatial Skill interaction predicting mathematics performance via spatial language comprehension (indirect effect).

The results revealed a significant moderation of gender on the relation between spatial skill and spatial language comprehension ($b = -0.83$, standard error [SE] $= 0.34$, $t = -2.46$, $p = .015$), such that the effect of spatial skill on spatial language comprehension was significant for only females ($b = 1.26$, $SE = .25$, $p < .001$) and not for males ($b = -0.43$, $p = .108$). When examining the indirect effect of spatial skill on overall mathematics performance through spatial language comprehension, the indirect effect was significant for females, ab = .35, 95% confidence interval (CI) [.17, .56], and not males, ab = .12, 95% CI [–.02, .29] (see Figure 2). The index of partial moderated mediation was −.23, 95% CI [–.46, −.04]. For females, the mediator could account for roughly half of the total effect ($P_M = .46$). Thus, spatial language comprehension partially mediated the relation between spatial skill and mathematics performance for females but not for males.

Discussion

This study investigated 3-year-olds' comprehension of spatial terms and phrases through the use of a novel spatial language measure. The use of a teddy bear and a bucket on each trial minimized linguistic difficulty by having different spatial terms appear as the only novel element in the sentence. Comprehension was used as the dependent variable so that children did not need to formulate verbal responses. Children's selection through touching or pointing at one of the three pictures in the display appeared enjoyable for children, given that children failed to respond on

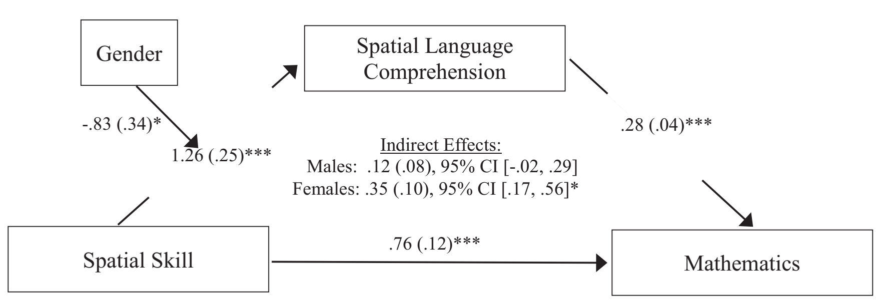

Figure 2. Moderated mediation model with only gender as the moderator. Socioeconomic status (SES) was not a significant moderator, so it was removed from the final model. Spatial skill is a composite of performance on the two- and three-dimensional trials of the Test of Spatial Assembly (2D and 3D TOSA, respectively; Bower et al., 2020). Mathematics is a composite of performance on the Test of Early Mathematics Ability (3rd ed.; TEMA-3) and Woodcock–Johnson-IV Applied Problems (WJ-AP) subtest. * $p < .05$. *** $p < .001$.

only .01% of the trials. We also asked whether comprehension of spatial terms differed for children based on gender or SES and whether a link would emerge between spatial language comprehension and children's scores on contemporaneous tests of mathematical and spatial skills.

What Prepositions Do Children at This Age Appear to Know?

Adding to previous research on preposition production (i.e., Brown, 1973; Fenson et al., 1994; Johnston & Slobin, 1979), we found that at 3 years of age, almost all children understand such prepositions as *in*, *up*, and *under*. Nevertheless, their comprehension of more complex prepositions and phrases that require reasoning about more than two objects (e.g., "The bear is between the buckets") or multiple axes of representation (e.g., "The bear is in front of the bucket" and "The bear is behind the bucket") is still developing; only 21.5% of children correctly identified these spatial relations. This finding complements other reports about the difficulty of spatial prepositions (Brown, 1973; Foster & Hund, 2012; Johnston, 1984; Johnston & Slobin, 1979; Washington & Naremore, 1978) while filling a gap in an area where research has primarily focused on language production (e.g., Weist et al., 2000).

In contrast to production, language comprehension takes away the necessity for the child to retrieve the correct term from memory. As such, we would expect children's comprehension of spatial language to precede their production. This study's findings go hand in hand with, for instance, the research reported by Johnston and Slobin (1979). They found, for example, that at 3.5 years of age, approximately 20% of children are producing the preposition *between*, whereas here, 44.3% of 3-year-olds correctly identified the photo representing this spatial term. A similar pattern was also found for *front*, with only 5% of 3-year-olds producing the term (Johnston & Slobin, 1979) and 55.2% of children at the same age correctly identifying *front* in the present study. Foster and Hund (2012) also found that at 4 years of age, children used *between* in an average of 12% of trials and *middle* on an average of 16% of trials. Comprehension of these two terms for 3-year-old children was notably higher in the current sample, with 44.3% correctly identifying *between* and 60.9% correctly identifying *middle*. As such, children's spatial language comprehension does appear to precede their spatial language production.

Socioeconomic Status and Gender Differences

We found pronounced differences in 3-year-olds' comprehension of spatial terms based on SES and gender. Even at 3 years of age, lower-SES children's spatial language comprehension (M = 60.6% correct) was significantly below that of their higher-SES peers (M = 73.6% correct), lending further support to previous findings of SES discrepancies in early general language (i.e., Fernald et al., 2013; Hart & Risley, 1995; Hustead, 1974; Levine et al., 2020) and mathematical language (Purpura & Reid, 2016). Male 3-year-olds also performed slightly below females on our assessment (by a differential of 0.8), which is surprising because most previous research has shown diminishing gaps in the linguistic development of males and females as children approach preschool (Huttenlocher et al., 2010; Rowe, 2012). Additionally, these findings directly contradict the findings of Pruden and Levine (2017), who found higher spatial language production in males than females, although this difference was fully mediated by parental differences in spatial language used with their children. One possible explanation for this discrepancy is that Pruden and Levine (2017) only looked at production, whereas this study examined language comprehension. A second possible explanation is that Pruden and Levine studied "what" spatial language that describes the world and properties of objects, such as dimensional adjectives (e.g., *little*), shape names (e.g., *circle*), and words that describe spatial features (e.g., *curvy*). The present study focused on "where" spatial language that describes the location of objects in space, such as *next to* or *in front of*. These differences may account for the opposing findings. Future work should examine if other types of spatial language may also mediate spatial skill and mathematics performance. Dimensional adjectives, for example, may help with spatial and mathematical scaling tasks (e.g., number-line estimation), whereas shape terms and words describing spatial features may be involved in property-based spatial analytic reasoning, which may be heavily related to geometric problem solving (e.g., Battista, Frazee, & Winer, 2018).

Although the present study did not find a significant interaction between gender and SES for children's spatial comprehension scores, lower-SES males seemed to perform worse than all other groups (see Table 4). This lends support to Barbu et al.'s (2015) finding that the language development of lower-SES males was lower than that of lower-SES females, although there was no gender difference among higher-SES 3-year-olds. Because lower-SES children are exposed to less child-directed language than their higher-SES peers (Hart & Risley, 1995), the additional input that higher-SES children receive may help higher-SES males overcome the early female advantage in language development. Future research should further investigate these SES discrepancies, particularly regarding lower-SES males. Such SES discrepancies in 3-year-olds' comprehension of spatial language may be particularly significant, considering the relationship between spatial language and spatial skill.

Associations of Spatial Language Comprehension, Spatial Skill, and Mathematics

We found that children's spatial language comprehension scores had a significant partial correlation with composite performance on 2D and 3D assessments of spatial skill, bolstering previous research (e.g., Balcomb et al., 2011; Miller et al., 2016; Polinsky et al., 2017; Pruden et al., 2011). It may be that having better spatial language comprehension helps individuals to encode the spatial relations of the shapes and blocks during the 2D and 3D TOSA. Prior work supports this notion by finding that the presence of spatial language can influence the way individuals encode and remember spatial relations in visual scenes (e.g., Feist & Gentner, 2007; Miller et al., 2016). Other work suggests an alternative explanation: Promoting children's attention to spatial information may be the underlying cognitive mechanism (Casasola, 2005; Gentner & Goldin-Meadow, 2003; Miller & Simmering, 2018). Knowing the appropriate spatial terms may help children focus on the relevant spatial dimensions.

In the current study, a multiple-regression model examined the associations between child gender, SES, spatial skill, spatial language comprehension, and the interaction between spatial skill and spatial language comprehension with children's mathematics performance. The current study's finding that preschoolers' spatial language comprehension predicts mathematics performance supports the limited previous findings that knowing spatial language may extend directly to mathematics performance (Purpura et al., 2017). Early spatial language comprehension may bolster children's mathematics skills through indirect and direct pathways. Indirectly, spatial language may help children learn and store the different spatial relations that may exist between objects (e.g., Casasola, 2010) and thus bolster the development of foundational spatial skills. Directly, spatial language may operate on attention by highlighting the spatial relations underlying mathematical concepts per se (e.g., numbers on a number line, fractions; e.g., Mix & Cheng, 2012; Verdine, Golinkoff, et al., 2017). This relation between early spatial language comprehension and mathematical skills is of significance in our increasingly technological world. As such, focusing on spatial language may well provide one key factor in facilitating mathematics achievement.

Moreover, in the multiple-regression model, the significant main effect of spatial skill and interaction between spatial language comprehension and spatial skill performance in predicting mathematics performance, along with findings from previous work that support a longitudinal association between children's spatial skill and mathematics performance (e.g., Bower, Odean, et al., 2020), prompted a larger, exploratory moderated mediation model. This larger moderated mediation model examined the potential of spatial language comprehension to act as a tool to further develop and connect spatial skills to mathematical learning by bolstering spatial and quantitative-relational reasoning. Moreover, because there were SES and gender differences on the Spatial Language Comprehension Task in the current study and because prior work supports SES differences (e.g., Verdine, Golinkoff, et al., 2017) and gender differences (e.g., Levine et al., 2016) in spatial skill, this moderated mediation model considered the roles of SES and gender as possible moderators.

The results indicated that gender was the only significant moderator, such that spatial language comprehension mediated the effect between spatial skill and mathematics performance, but for females only. Even though these findings are opposite of the original prediction, it is possible that spatial language comprehension may serve as a tool for young females to bolster basic spatial and mathematics skills. Even though there was no gender difference on the TOSA composite in the current study, it could be that the pathway between spatial skill and mathematics knowledge for females is more complex than it is for males and thus requires additional cognitive resources or experiences. This may be one reason why spatial language comprehension may help progress this association between spatial and mathematics skills for females.

Interestingly, SES did not moderate the mediation effect of spatial language comprehension on the association between spatial skill and mathematics. Prior work provides evidence that early language mediates the association between children's home environments (e.g., for which SES can be considered a "stand-in") and school readiness, such that lower SES predicts less exposure to reading, which in turn has a negative effect on school readiness (e.g., Forget-Dubois et al., 2009). In the current study, it may be that lower-SES children received insufficient exposure to spatial language, and thus spatial language comprehension was not helpful for aiding the association between spatial skill and mathematics performance. Moreover, because higher-SES children were already performing better on the TOSA composite, Spatial Language Comprehension Task, and mathematics outcome compared with their lower-SES peers (for statistics, see Supplemental Table S1 in the online supplemental material), there was little room for an indirect effect of spatial language comprehension.

Limitations and Future Directions

Although these findings are noteworthy, this was a correlational study; we cannot be certain about the directionality of the associations found. However, recent work by Purpura et al. (2017) further indicated that the direction is from spatial language to mathematics. Moreover, although we found that gender moderates the mediation of spatial language comprehension in the association of spatial skill and mathematics performance, the causal mechanisms behind these discrepancies are not clear. Thus, given the uncertainty of these results, future studies should first replicate this finding and then examine potential causal links between spatial language comprehension and mathematics and spatial performance. Additionally, although we present descriptive information for each item in the Spatial Language Comprehension Task by gender and SES, we examined only the total correct on the task as a whole because the Spatial Language Comprehension Task did not include multiple trials for each word. To examine performance on individual words, future work should include multiple trials of each word, possibly instantiated by multiple familiar objects.

Another limitation of the current study was that we examined broad measures of spatial skill (composite of the 2D and 3D TOSA), spatial language comprehension, and mathematics performance (composite of WJ-AP and TEMA-3 subtests). Even though the current study supports the view that spatial language comprehension mediates the association between spatial skill and mathematics performance for females only, future work should further examine the specificity of these associations. For instance, prior work suggests that certain mathematical tasks are associated with larger variance in spatial skill than others and that performance on certain spatial tasks was a better predictor of mathematical performance (Mix et al., 2016). Specifically, Mix et al. found that place value and calculation tasks predicted the most variance in spatial skill and that mental rotation was the best predictor of mathematical performance in kindergarten. Thus, parsing mathematics knowledge or spatial language comprehension into subcategories may yield finer associations.

Conclusion

Three-year-olds from both higher- and lower-SES groups comprehend a sizable number of spatial terms, as indicated by their performance on a novel spatial language comprehension measure. Yet, there were pronounced differences in children's comprehension of spatial terms based on gender and especially on SES, such that boys and low-SES children knew the fewest spatial terms. This new spatial language comprehension measure is not only quick and easy to administer, but children also seem to generally enjoy it. Thus, this measure could be useful for early childhood professionals or researchers examining the early space–math link. Moreover, because few studies have included lower-SES children, the present findings are concerning given that spatial language relates strongly to performance in mathematics—even after reducing the influence of children's productive vocabulary scores and child age. With lower-SES preschoolers already struggling in spatial, mathematics, and language development relative to their higher-SES peers, these findings beg for intervention. Additionally, the mediating effect of spatial language comprehension on the association between spatial skill and mathematics performance for females provides the foundation for the important next step of testing this potential causal and directional influence. Perhaps explicitly teaching children spatial terms that are not commonly taught can help children better handle the complex relations embodied in many scientific concepts and mathematical expressions.

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