Gesture and Speech Input are Interlocking Pieces: The Development of Children's Jigsaw Puzzle Assembly Ability

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Abstract

Spatial reasoning ability is enhanced by spatial activities and spatial language. Spatial games (e.g., block building, assembling jigsaw puzzles) are often accompanied by spatial language, which, in turn, is often accompanied by co-speech gesture. Here we investigate the effects of spatial language and gesture in the context of puzzle play in improving preschool children's puzzle assembly ability. We do this by conducting a training study in which we independently manipulate the presence of spatial language and the presence of gesture in the context of four jigsaw puzzle training sessions. Our findings show that providing co-speech gesture along with spatial language is particularly effective in improving children's ability to put together puzzles on their own.

Keywords: spatial cognition; gesture; puzzle play; preschool children; spatial language; STEM

Introduction

A growing body of research supports a positive relationship between spatial skills and success in the STEM (science, technology, engineering, and mathematics) disciplines. This relationship holds across a wide range of ages, from preschoolers to older children and adults (e.g. Gunderson, Ramirez, Levine, and Beilock, 2012; Verdine, Golinkoff, Hirsch-Pasek, Newcombe, Filipowicz, and Change, 2013; Mix & Cheng, 2014; Benbow, Lubinski, Shea, and Eftekhari-Sanjani, 2000; Shea, Lubinski & Benbow, 2001; Wai, Lubinski, & Benbow, 2009). Further, spatial skills mediate the frequently reported relationship between gender and mathematics performance (Casey, Nuttall, & Pezaris, 1997; Casey, Nuttall, Pezaris, and Benbow, 1995). These findings illustrate the role of spatial skills in core academic subjects and highlight the importance of improving those spatial skills beginning early in life. In the current study, we experimentally manipulate the availability of two sources of input – spatial language and co-speech gesture – that are correlated with spatial thinking, (e.g., Levine, Ratliff, Huttenlocher and Cannon, 2012; Pruden, Levine & Huttenlocher, 2011).

Sex differences in spatial tasks, such as mental rotation, may, at least partly, reflect differences in how frequently boys and girls are exposed to spatial activities at young ages (Baenninger and Newcombe, 1995). Experience with play activities that rely on spatial skills predicts performance on academic achievement measures, whether the activity is playing with LEGOs, wooden blocks, or jigsaw puzzles (respectively, Wolfgang, Stannard, and Jones, 2003; Casey, Andrews, Schindler, Kersh, Samper, and Copley, 2008; Levine et al. 2012). However few studies have experimentally manipulated the specific types of input provided to children in play in order to evaluate whether they have a causal effect on improving spatial abilities. In this study, we manipulated whether spatial information was provided in both speech and gesture in order to test whether the spatial language and gesture that occur naturally during puzzle play actually lead to, as opposed to merely being correlated with, improvements in children's spatial thinking and spatial skills.

Spatial Language and Gesture

Spatial language input predicts performance on spatial activities (Casasola, 2005; Lowenstein & Gentner, 2005; Pruden & Hirsh-Pasek, 2006). Children who do not acquire spatial language lack words for spatial relationships, and this deficiency is correlated with poor performance even on *non-verbal* spatial tasks (as in deaf Turkish children who could not learn spoken language, had no access to sign language, and had not invented gestures for spatial relations; Gentner, Özyürek, Gürcanli, and Goldin-Meadow, 2013). The effect of knowing relevant spatial terms on performing a spatial task has also been tested experimentally. Children who produce an appropriate term for a spatial concept like "left" or "above" perform better in search and navigation tasks than children who do not produce these terms (Gentner, 2003; Shusterman, Lee, and Spelke, 2011; Hermer-Vazquez, Moffet, and Munkholm, 2001).

The acquisition of spatial terms is influenced by environmental input at home and at school. A longitudinal study of children's language development shows that parent

spatial language use predicts children's use of spatial language, which in turn predicts their performance on non-verbal spatial tasks, including a spatial transformation task and a spatial analogies test (Pruden *et al*., 2011). Moreover, parent spatial language accompanied by gesture predicts children's spatial language better than parent spatial language that is not unaccompanied by gesture (Cartmill, Pruden, Levine and Goldin-Meadow, 2010). Previous experimental work has shown that when children are given instruction in both gesture and speech, children integrate the information provided in the two modalities and gain a deeper understanding of the concept (e.g., Piagetian conservation; Church, Ayman-Nolley, and Mahootian, 2004; Ping and Goldin-Meadow, 2008). Gesture has the potential to play a central role in learning spatial tasks because it is itself spatial and thus can transparently illustrate spatial concepts. Indeed, gesture may provide a bridge from spatial language to the world by linking spatial words to the features of the spatial world they represent (e.g., tracing a straight edge when explaining "this part is straight").

In the context of spatial activities, spatial input from adults may have a particularly strong impact on learning. The amount of spatial language parents used during puzzle play with their children predicted children's later mental transformation skills, but the effect was only found for girls (Levine *et al*. 2012). The lack of a relationship in boys may be attributable to the fact that parents used more spatial language overall with boys during puzzle play (i.e., perhaps all boys were getting "enough" spatial language). Gesture input may be particularly important in physical spatial tasks like puzzle play, but the respective contributions of gesture and spatial language input during spatial play have not been studied systematically.

The Present Study

We gave children training modeled after the naturalistic puzzle play children engage in with caregivers (Levine *et al*. 2012). We scripted the kinds of speech and gesture that naturalistically occurs when parents instruct their children in puzzle play in order to test whether these aspects of input improve children's subsequent spatial skill.

Our study explored (1) whether jigsaw puzzle ability could be improved through training, and (2) whether spatial language and gesture input work together during puzzle play to improve children's spatial skills (as measured by the ability to assemble a jigsaw puzzle). We were also interested in whether puzzle training provides children with an opportunity to develop their spatial abilities more generally, particularly those involved in performing mental transformations and understanding spatial relations. We hypothesized that spatial language and the gestures that accompany this language both provide important spatial information and that, when used together, the two would have a greater effect on the development of children's spatial skills than either modality on its own.

Study Overview

The study tested preschool children in a pretest-training-posttest design in which children were randomly assigned to one of four training conditions (described below). The study involved a total of 7 days of testing spread over a two- to three-school-week period. It involved 2 pre-test days, 3 training days that involved teaching with 4 different puzzles, and 2 post-test days. All tasks were videotaped to corroborate their results and were later coded. Missing data was excluded, and not imputed.

Participants

Seventy-five preschool-aged children (40 boys) participated in the study. The mean age of participating children was 57 months (SD=5.1 months, range 48-68 months). Thirty-five additional children began the study but were excluded during testing because they missed days of school during the training or testing period or expressed a desire to quit. The children attended one of 5 preschools (four public schools and one private school) in the Chicago Public School system. The schools varied in the average socioeconomic status of their students. The average percentage of students who were on free or reduced lunch programs across schools was 83.9%. The population was diverse in terms of race and ethnicity; according to demographics questionnaires returned by parents of students who chose to take part in the study, 48% of students identified themselves as Caucasian, 33% identified as African American, 14% identified as Asian, 2% identified as American Indian, and 4% identified as other. Additionally 25% of subjected reported they were of Hispanic ethnicity.

Design

Pre-test/Post-test The pre/post-test was administered during two 30-minute sessions given on two days and assessed a variety of spatial skills. All children received the same 5 tasks; a puzzle assembly task, the Children's Mental Transformation Test (CMTT; Levine, Huttenlocher, Taylor, and Langenrock, 1999), a spatial analogies test adapted from the Primary Test of Cognitive Skills (Huttenlocher & Levine, 1990), the Test of Relational Concepts (TRC; Edmontson and Thane, 1992), and a spatial language production task. The assessment of puzzle assembly skill served as the near transfer from the training task since it was a similar but unrelated puzzle, and tests of mental transformation, spatial analogy and spatial relational language served as far transfer tasks.

Pretest On Day 1 children completed the TRC and CMTT. On Day 2, children completed the spatial analogy task, the puzzle assembly task (in which children were given 5 minutes to assemble a 24-piece jigsaw puzzle), and a spatial language production task (in which children were asked to tell an experimenter how to assemble a 12-piece puzzle,

which was designed to elicit spatial language from the child; due to the high rate of non-compliance on this task, the results are not discussed here).

Training On Day 3 children received training on two 24-piece puzzles. On days 4-5 children received training with two 48-piece puzzles, one on each day.

Posttest On Days 6-7, children repeated the pre-test. No items changed between the pre- and post-test except for the 12-piece puzzle used in the spatial language production task. Children who were absent from school during the testing period resumed testing where they left off when they returned, but training never preceded Posttest by more than 7 calendar days.

Puzzle Assessment The near transfer task was a puzzle assessment in which children were given 5 minutes to assemble as much of a 24-piece jigsaw puzzle as they were able to complete on their own. This puzzle was identical in the pre-test and post-test. The puzzle was contained within a wooden frame, with 24 wooden pieces depicting animals and a landscape. The experimenter was present during assembly, but offered no help other than generic encouragement and prompting if the child began to lose interest. At the end of 5 minutes, children were offered help in finishing the puzzle if they had not completed it.

Children were given a puzzle piece location score and a puzzle piece connection score (both ranging between 0 and 24). Puzzle piece location score was determined by counting the number of pieces that were within a one-puzzle-piece radius of their correct position in a properly completed puzzle. The puzzle piece connection score was determined by tallying the number of puzzle-pieces on the board that were interconnected (making a score of 1 impossible). Scoring was completed using a screen shot of each child's performance 5 minutes following the beginning of the task.

Transfer tasks Children were given three additional spatial tasks designed to test their spatial language and reasoning ability. The spatial language tasks we provided were a modified version of the *Test of Relational Concepts* (TRC; Edmontson and Thane, 1992). The TRC tested children's comprehension vocabulary of spatial words by asking them to identify a picture that illustrates a spatial word. The spatial reasoning tasks consisted of a test of mental transformation and a test of spatial analogy. In the *Children's Mental Transformation Task* (Levine, Huttenlocher, Taylor, and Langenrock, 1999), children were shown images depicting two target pieces (symmetrical halves of a dark shape) that they were asked to mentally assemble, in order to identify the correct whole among an array of four shapes. The *spatial analogy task* was adapted from the Primary Test of Cognitive Skills (Huttenlocher & Levine, 1990). The task tested children's ability to generalize spatial relationships between objects in sets of pictures

Training The study used a training paradigm in which each child assembled puzzles with an experimenter; the experimenter provided different input depending on the training condition to which the child was randomly assigned. All children received the same amount of experience with the puzzles but varied along two dimensions: (1) language, containing eitherspatial or non-spatial descriptors of the puzzles and (2) co-speech gesture, indicating spatial aspects of the puzzle or entirely absent. Figure 1 presents an example of the language and gesture provided in each of the four experimental conditions.

During training, the experimenter and child took turns placing pieces in the puzzle. The order in which each piece was placed in the puzzle was predetermined and the experimenter handed pieces to the child so there was no search element involved in selecting a piece. The language and gesture that the experimenters used was scripted to tightly control the spatial and non-spatial language and co-speech gesture the children received within each condition.

The experimenter typically described the features of their pieces before they put them in and then remarked on the pictures or features of the puzzle that became visible after inserting a piece. A few times during each puzzle the experimenter attempted to put a piece in the incorrect location or with the incorrect orientation and then narrated the corrections (e.g., "I have to turn it right-side up before it will fit"). The experimenter also commented on some of the children's pieces once they had been correctly placed. If children had difficulty placing a piece, experimenters prompted the child up to three times using generic prompts (e.g., "try it another way/place") before finally pointing to the correct location.

	SPATIAL LANGUAGE (SL+)	**NO SPATIAL LANGUAGE (SL-)**
GESTURE (G+)	This piece has two straight sides ***[trace corner on piece]*** so it will fit in one of the corners ***[trace top corners in frame]***.	This piece has some light blue colors ***[trace corner on piece]*** so it will go in the sky ***[trace top corners in frame]***.
NO GESTURE (G-)	This piece has two straight sides, so it will fit in one of the corners.	This piece has some light blue colors, so it will go in the sky.

Figure 1: Sample experimenter language and gesture used to describe a puzzle piece in the four experimental conditions.

Spatial Language In the two conditions that included spatial language, experimenters used spatial words to refer to (1) *dimensions*, *features,* and *shapes* (e.g., small, curvy, straight, corner, border, square, circle), (2) *orientations* and *transformations* (e.g., upside-down, turn, flip), (3) *locations* and *directions* (e.g., behind, next to, left), or (4) *physical connections* (e.g., fits, connects, lines up with). In the non-spatial language conditions, the experimenter referred to properties of the images on the pieces using (1) *colors* and *textures* (e.g., red, yellow, sandy, wooden), (2) *actions or emotions* (e.g., playing, splashing, happy, excited), (3) *landmark features of the natural world* (e.g., sky, ground, trees), or (4) *pattern and outline matching* (e.g., goes/doesn't go, matches). Deictic language (e.g., "I think it goes here/there") was minimized in all conditions, so that children who received gesture input would not have access to unique information (i.e., by seeing points during deictic language).

Gesture Gesture information was provided either by directly illustrating spatial concepts (e.g. holding the forefinger and thumb in an "L" shape to represent a corner piece), or by tracing spatial features on the puzzle pieces or frame (e.g., tracing a straight edge of the frame). The gestures used were the same in the two gesture conditions and accompanied by a phrase containing either terms referring to spatial or non-spatial properties of pieces. For example, a gesture in which the experimenter dragged her finger down a completed side of a jungle puzzle was accompanied by "Good job! You finished the left side of the puzzle" in the spatial language condition, and "Good job! Now we can see three different kinds of plants" in the non-spatial condition.

Results

Relations among tasks

We examined the relationship between sex, age, and pretest measures of puzzle assembly and spatial ability. We found no significant relationship between sex and any of our spatial measures. Age was significantly related to puzzle assembly, in both location (r=.25) and connection (r=.26, *p*s<.05). Age was also significantly related to performance on the TRC (r=.44, *p*<.01), but not to the other spatial measures. Within the puzzle assembly measures, location and connection scores were very highly correlated (r=.96), *p*<.01). We therefore summed these scores to create a composite measure of puzzle assembly skill (used for the remainder of our analyses). Within the measures of spatial skill, the TRC was significantly related to the spatial analogies test (r=.39) and CMTT (r=.48), and the spatial analogies test and CMTT were also significantly related (r=.50, *p*s<.01). The puzzle assembly measure was significantly related to all other spatial measures, as shown in Table 1. In sum, the correlations show that puzzle assembly skill and other spatial assessment measures that are widely used in the field are related.

Table 1. Relations Among Puzzle Assembly Ability and Spatial Skills

Measure	Puzzle Assembly	Test of Relational Concepts (TRC)	Spatial Analogies (SA)	Children's Mental Transformation Task (CMTT)
Puzzle	1			
TRC	0.35	1		
SA	0.34	0.39	1	
CMTT	0.35	0.48	0.5	1

Pretest to Posttest Changes Transfer tasks and the puzzle assembly measure were analyzed using a 2 (–gesture/ +gesture) X 2 (–spatial language/+spatial language) repeated measures ANCOVA, controlling for child age.

Puzzle Assembly We investigated how gesture and spatial language interacted in children's improvement in puzzle assembly. We observed an interaction between spatial language and gesture on children's improvement in puzzle skill, $F(1,70)=4.1$, $p<.05$, $\eta_p^2=.06$ (Figure 2). Bonferroni-corrected post-hoc analyses showed a significant difference between experimental conditions $F(3,70)=2.98$, $p<.05$. The interaction was driven by a difference between children in the two spatial language conditions; children who received co-speech gesture with spatial language had significantly higher scores than those who received spatial language without gesture.

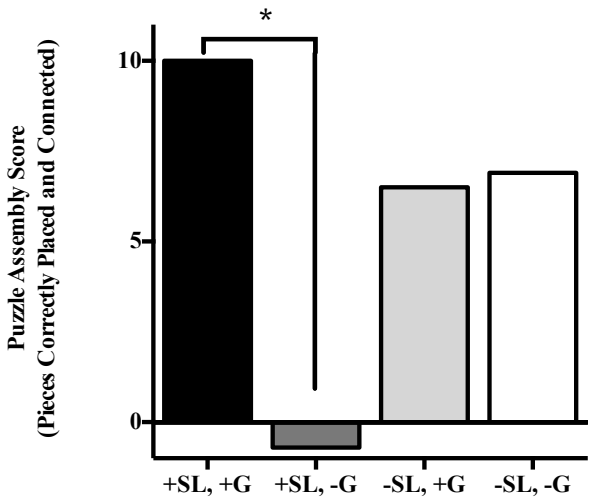

Figure 2: Pretest-Posttest change in Puzzle Assembly Score

Transfer Tasks We examined the effect of spatial language and gesture during training on gain scores on the CMTT, Spatial Analogies Test, and TRC, controlling for age. We did not find any improvement across any of the tasks.

General Discussion

In this paper we examined the effectiveness of various puzzle play interventions in promoting children's spatial skill. We also evaluated how various commonly used measures of spatial ability relate to puzzle play proficiency in young children. With respect to our first question, we found that preschool children's performance on multiple verbal and non-verbal spatial tasks were modestly correlated and related to puzzle assembly skill. We did not find any differences associated with sex on spatial ability at this young age range.

With respect to the role that spatial language and gesture play in the development of spatial skill, our findings demonstrate the facilitative effect that gesture has on spatial language during children's puzzle assembly. Our results do not support a simple "more is better" theory regarding spatial language input; children in our study did not benefit from simply hearing spatial language. Rather, the quality of the input mattered, and the presence of co-speech gesture conveying relevant spatial information was an important indicator of quality of input. Spatial gestures may disambiguate potentially unclear spatial language, and may thus be critical to understanding the typical directions parents provide in a spatial task. These gestures may also contribute to children's spatial skill by providing enriching information in the form of concrete and dynamic analogue information about particularly relevant pieces of spatial information (Krauss, Chen, and Gottesman, 2000).

Our findings also bear on basic questions about how information contained in speech and gesture interact (Alibali and Goldin-Meadow, 1993; Dick, Goldin-Meadow, Solodkin and Small, 2012; Kelly, Creigh, and Bartolotti, 2010). Gesture may provide children with an immediate, concrete exemplar of the spatial terms they hear. Gestures are frequently used when defining spatial terms (Krauss, 1998), and providing gesture and speech together promotes learning new concepts (Church, Ayman-Nolley, and Mahootian, 2004). Observing gestures may also signal to children that they should prepare to make (or simulate) manipulations to objects. It is also possible that gesture renders accompanying speech more engaging and accessible to children, rather than adding spatial information of its own. Further research is needed to understand the various ways in which the co-speech gestures that commonly accompany spatial language contribute to the child's learning. The current study, however, provides evidence that gestural input does contribute to learning in the spatial domain.

Learning to put the pieces of a puzzle together is based both on one's visuospatial abilities and on learning appropriate strategies (Dykens, 2002; Verdine, Troseth, Hodapp and Dykens, 2008). Children's spatial abilities and strategies are likely influenced by the input they receive from caregivers; children's performance on spatial measures is strongly related to both parent speech and gesture (Pruden, *et al.* 2011; Ehrlich, Levine, and Goldin-Meadow, 2006). The interplay of these factors in the home is difficult to disentangle, but our results support the previous finding that parent gesture explains unique variance in children's spatial language (Cartmill *et al*. 2010), and also suggests that gesture accompanying spatial language contributes to the development of children's spatial thinking. Although we provided only a brief intervention (experience with 4 puzzles over 3 days), the effect of combining spatial language and gesture over time might contribute to the development of strong spatial thinking, not only on near transfer tasks but perhaps more broadly.

Beyond showing the significant benefit to be garnered with even a short training regimen in a spatial task when providing gestural cues, these results bear on larger questions of how to support the development of young children's spatial skills. Our findings suggest that spatial language with co-speech gesture might provide a learning tool that, over time, could benefit skill development in this important domain.

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