

# Spatial Skills Predict Mathematics Knowledge in Preschool

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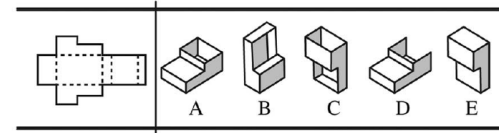


NCTM Research Conference 2017

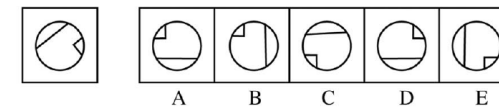


## Try These Tasks

- Pick the object which shows just how the piece of flat metal will look when it is folded at the dotted lines. When it is folded, no piece of metal overlaps any other piece or is enclosed inside the object.



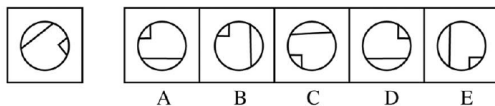
- Choose the one drawing which, when turned around or rotated, is exactly like the basic drawing at the left.



From Wai, Lubinski & Benbow (2012)

## What Are Different Components of Spatial Skills?

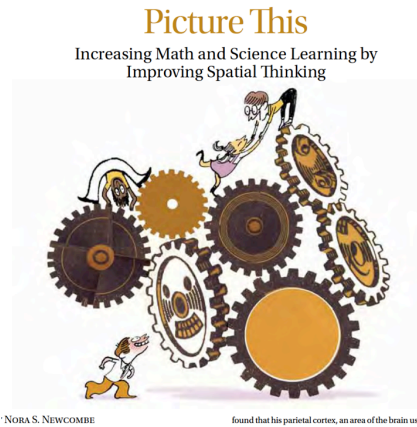
- Large variety of types and measures of spatial skills. Two very common types are:
- **Spatial visualization** - the ability to imagine and mentally transform spatial information (Uttal et al., 2013). Tasks you just did fit here.
- **Visual-spatial working memory** - the ability to hold the locations of different objects, landmarks etc. in memory (Raghubar, Barnes, & Hecht, 2010). Popular game “Simon” taps this skill.



## Spatial Skills and STEM Success

- High school students with high spatial skills are much more likely to earn a degree and have a job in mathematics, computer science, engineering or the physical sciences, controlling for verbal and math abilities (Wai, Lubinski & Benbow, 2009)

## Spatial Skills and Math Knowledge in School-Age Children <sup>5</sup>



- Spatial skills are related to math knowledge in school-age children (Gunderson et al., 2012; Mix & Cheng, 2012; NRC, 2009)
  - Limited evidence that improving spatial skills improves math knowledge (Cheng & Mix, 2013; Lowrie, Logan & Ramful, 2017; but see Hawes, Moss, Caswell & Poliszczuk, 2015). Other studies in progress.

## Spatial Skills and Math Knowledge: Relations in Young Children <sup>6</sup>

- Emerging evidence indicates related very early:
  - Spatial skill at age 3 related to math knowledge at age 5 (Verdine et al, 2017).
  - Spatial skill in infancy related to math knowledge at age 4 (Lauer & Lourenco, 2017)

## Why Do Spatial Skills Relate to Early Mathematics Development? <sup>7</sup>

- Attending to which spatial skills are most strongly related to early math knowledge offers some clues to potential mechanisms.
- **Spatial visualization**, the ability to imagine and mentally transform spatial information, may help children mentally represent quantities and relationships between them.
  - E.g., Placing numbers on number lines, which is a spatial representation of number (Gunderson et al., 2012)
- **Visual-spatial working memory** - the ability to actively maintain and manipulate the locations of different objects in memory, is often required for spatial-based solutions to math problems. May also help children process instruction that includes visual and spatial information, allowing them to link new information to information they already know.
- **Form Perception**: the ability to copy and distinguish shapes from other shapes and to decompose them into parts, is likely involved in learning about geometric shapes, visual patterns and written numerals.
  - E.g., Identifying patterns and the pattern unit in visual patterns is strongly related to form perception skill (Rittle-Johnson & Zippert, in preparation)



## Do Spatial Skills Vary Across Groups in Young Children? <sup>8</sup>

- Differences by sex or family socio-economic status (SES) in preschool?
  - Sex Difference: May begin late in preschool
    - Boys and girls did not differ in spatial visualization skill at age 3 (Verdine et al., 2017)
    - Boys substantially better in spatial visualization starting at age 4.5 (Levine et al, 1999)
  - Higher-SES group had higher spatial skills than lower-SES group at age 3 (Verdine et al., 2017)

## Current Research

- Goals
  - Confirm relation between spatial and math knowledge in preschool
  - Explore which spatial skills have the strongest relation with math knowledge in preschool
  - Explore differences based on sex and family income
- Studies
  - Study 1: Spatial skills predicting math knowledge at same time point. Diverse sample of children, so examine sex and SES differences.
  - Study 2: Spatial skills predicting math knowledge 3 months later.

## Study 1

- 77 preschoolers, ages 4.0 to 5.2 months (mean = 4.5 yrs)
  - From 6 preschools (3 public school, 1 head start, 2 private)
  - Sex: 37 boys and 40 girls
  - 53% Ethnic minorities
  - Financial Assistance:
    - 35 (45%) none
    - 15 (20%) some assistance
    - 27 (35%) full assistance (qualify for free or reduced priced lunch)
- 3 Spatial Tasks:
  - Form perception
  - Spatial visualization
  - Visual-Spatial working memory
- Math Assessment
- Verbal intelligence as control variable

Rittle-Johnson & Zippert, in prep

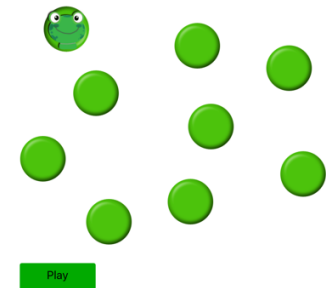
## Spatial Assessments

- Form Perception: Position in Space from DTVP-2:
  - Identify the image in the same position as the model image
- Spatial Visualization: Block Design from WPSI-IV
  - Reproduce the model or picture using colored blocks



## Spatial Assessments Cont.

- Visual-Spatial Working Memory: *Path Span* eCorsi task
  - Reproduce the path in the same order or in reverse order
- Created composite spatial score as well



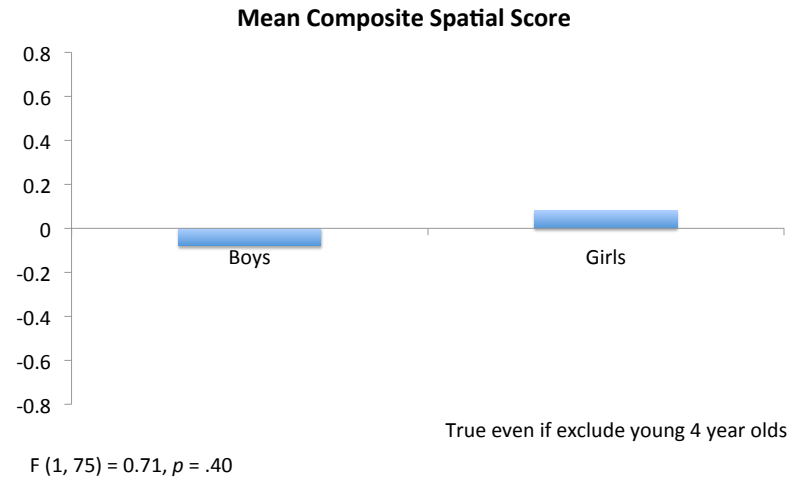


# Math Knowledge

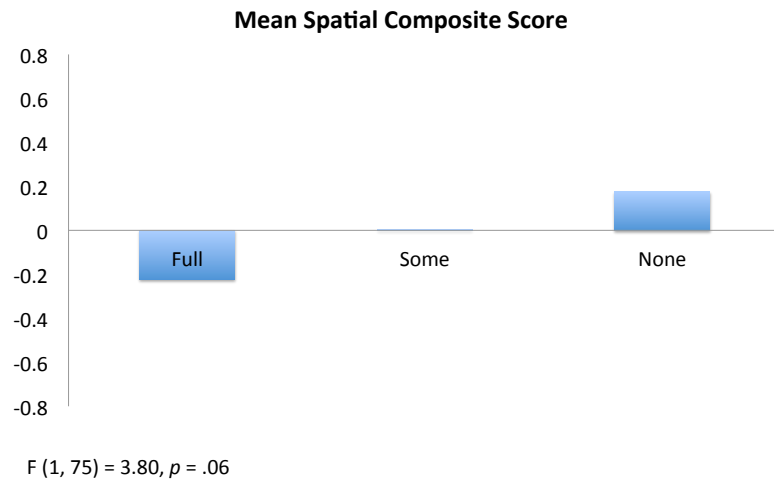
*Research-Based Early Mathematics Assessment (REMA)*  
 – *Short Form* (Weiland, Wolfe, Hurwitz, Clements, Sarama & Yoshikawa 2012).

Math Topic	Sample Item
<b>Non-symbolic Quantity</b>	Shown two cards, with 4 dots and 3 dots: 'Which one has more?'
<b>Counting</b>	Shown 4 objects in a line: "'I'm going to show you some food boxes. Please tell me how many I have.'
<b>Symbolic Mapping</b>	Match the numerals 1-5 to the appropriate number of grapes.
<b>Shape</b>	Select all triangles from a collection of 24 shapes; some are prototypic shapes and some are not.

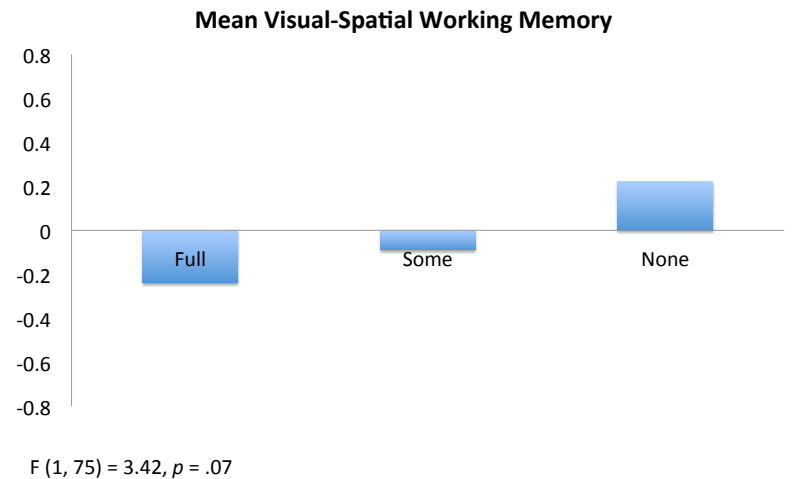
# Spatial Skills Did Not Differ by Sex



# Spatial Skills Differed by Financial Assistance Level

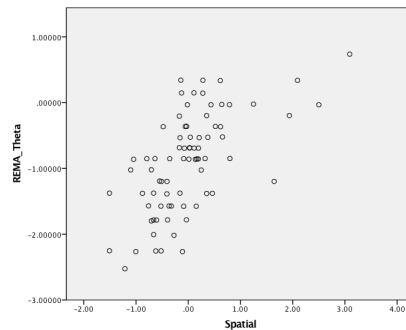


# Spatial Skills Differed Most for Visual-Spatial Working Memory



## Spatial Skill and Math Knowledge

- Math knowledge did not differ based on sex or financial assistance.
- Spatial skills were related to math knowledge,  $r(76) = .62$ , even after controlling for age and verbal intelligence,  $r(76) = .49$ .



## Study 1 Summary

- Boys and girls did not differ in spatial skills in preschool, but children from higher-income families had higher spatial skills, esp. visual-spatial working memory
- Spatial skills in preschool strongly correlated with math knowledge at same time point.
  - Form perception and spatial visualization skills in particular were unique predictors of math knowledge.

## Which Spatial Skills?

Variable	$\beta$	$t$
Age	.17	1.69 $\tau$
Verbal intelligence	.13	1.18
<b>Form Perception</b>	.24	2.10*
<b>Spatial Visualization</b>	.18	1.77 $\tau$
Visual-Spatial Working Memory	.19	1.51

\* $p < .05$ ,  $\tau p < .10$

Form perception and spatial visualization were uniquely related to math knowledge at the same point in time.

## Study 2: Spatial Skills and Later Math Knowledge<sup>20</sup>

- 42 preschoolers, ages 4.0 to 5.7 months
  - Recruited from private preschools
  - Sex: 25 boys and 17 girls
  - 16% Ethnic minorities; Financial assistance unknown (but rare)
- 3 Spatial Tasks given in winter:
  - Form perception
  - Spatial visualization
  - Visual-Spatial working memory
- Math Assessment given 3 months later

## Results

- Spatial skills and math knowledge did not differ based on sex.
- Spatial skills were related to math knowledge,  $r(32) = .78$ , even after controlling for age and verbal intelligence,  $r(29) = .73$ .

## Results

Variable	$\beta$	$t$
Age	.20	1.53
Verbal intelligence	.11	0.91
Sex	.05	0.35
<b>Form Perception</b>	.34	2.43*
<b>Spatial Visualization</b>	.28	2.17*
<b>Visual-Spatial Working Memory</b>	.25	1.76 <sup>†</sup>

\* $p < .05$ , <sup>†</sup> $p < .10$

Each spatial skills was a unique predictor of math knowledge 3 months later.

## Answering Our Research Questions

- Confirmed relation between spatial and math knowledge in preschool
- Explored which spatial skills have the strongest relation with math knowledge in preschool:
  - Consistently related:
    - **Form perception** - the ability to copy and distinguish shapes from other shapes and to decompose them into parts.
    - **Spatial visualization** - the ability to imagine and mentally transform spatial information (Uttal et al., 2013)
  - Less consistently related
    - **Visual-spatial working memory** - the ability to hold the locations of different objects, landmarks etc. in memory (Raghubar, Barnes, & Hecht, 2010)
- Explore differences based on sex and family income
  - Boys and girls in preschool did not differ in spatial skills in our studies.
  - Children from higher-income families did have higher spatial skills, esp. visual-spatial working memory

## Educational Implications: Developing Spatial Skills

- Playing with blocks, puzzles and videogames and exposure to spatial language seem to support spatial skills (Levine, Ratliff, Huttenlocher, & Cannon, 2012; Newcombe, 2010; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014; Verdine, Golinkoff, Hirsh-Pasek, Newcombe, et al., 2014).
- Spatial skills can be improved with targeted training (Uttal et al., 2013)!
  - For example, kindergarten children improved in their spatial visualization skill after guided block play with a teacher (Casey et al., 2008).



## Educational Implications: Spatial Skills and Mathematics

25

In turn:

- **Form Perception** may help children learn about geometric shapes, visual patterns and written numerals, which each require distinguishing and decomposing visual forms.
- **Spatial visualization** may help children mentally represent quantities and relationships between them.
  - E.g., Support development of mental number line (Gunderson et al., 2012)
- **Visual-spatial working memory** may help children process instruction that includes visual and spatial information, linking new information to information they already know, growing their mathematics knowledge over time.

## Acknowledgements

26

Children's Learning Lab



Funding Sources

IES grant R305A160132 to  
Rittle-Johnson



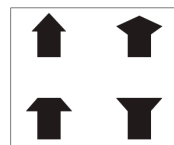
## Spatial Assessments

27

- Form Perception:  
Position in Space from  
DTVP-2:



- Identify the image in  
the same position as  
the model image



Choice Array

- Spatial Visualization:  
Children's Mental  
Transformation Task  
(Levine et al., 1999)



(b) Diagonal translation (c) Direct rotation (d) Diagonal rotation

Four types of Pieces Cards for above Choice Array

- Point to the picture the  
pieces make.

## Spatial Assessments Cont.

28

- Visual-Spatial  
Working Memory:  
Corsi Block task  
(Pagulayan, et al., 2005)
  - Reproduce the path  
in the same order or  
in reverse order

