Developing relations between spatial knowledge and spatial language in human children

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ABSTRACT

One of the hallmarks of human intelligence is the ability to quickly extract and encode spatial relations. Yet little is known about how this ability evolved, about its relation to human language, and about the neural mechanisms that support it. We have begun to examine the development of spatial cognition using a developmental approach to shed light on these issues. We have two alternative hypotheses: 1) the same underlying mechanisms operate in processing two sets of spatial relations – above/below (A/B) and left/right (L/R), or (2) different mechanisms are involved and are reflected by the order in which terms for these relations are learned by human children. We tested these hypotheses by examining the performance of children between 5 and 11 years old on a verbal and nonverbal task of spatial reasoning. We will follow up this study with an investigation of the neural processing of these relations in adults.

OBJECTIVES & INTRODUCTION

The role of language in spatial cognition remains a controversial topic.

(1) Some evidence suggests that language plays an important role:

a. Language has been shown to facilitate the extraction and encoding of relational information (Hayward & Tarr, 1995; Gentner , 2003).

b. Hermer and Spelke (1996) offer evidence indicating that language is necessary for accurate reorientation in a spatial environment.

c. Levinson (1996) showed that whether a language codes spatial information in terms of north-south or right-left coordinates affects speakers ' representations of object locations.

d. More generally, work in other domains (color and number) suggests that language provides a unique platform upon which decisions are made about categorical and quantitative aspects of objects.

(2) Other findings, however, question these effects:

a. The facilitative role of language has not always been found (Munnich & Landau, 2003).

b. The re-orientation effects reported by Hermer & Spelke have been show to vary as a function of room size and other variables unrelated to language knowledge (Ratliff & Newcombe, 2008).

c. Li & Gleitman (2002) found English speakers were able to successfully shift their frame of reference strategy from a relative to an absolute system when landmarks were available for external reference.

d. Recent work by Goodwin et al. (2012) indicates that monkeys are able to successfully answer *above, below, right,* or *left* in a relational task even without language to guide their performance.

Thus, it remains unclear how these abilities influence each other in development. Remarkably, verbal and nonverbal knowledge of the concepts *above, below, right* and *left* has not been examined within one group of children as a function of age.

The goal of this project is to offer evidence on how verbal and nonverbal knowledge of these concepts develop in relation to each other.

Documenting the development of these words and concepts in human children may offer evidence on how these abilities evolved, and may offer clues about the evolution of the neurological mechanisms that support these abilities.

METHODS

Participants:

Children from the age of 5;0 to 10;11 participated (N=118).

Tasks:

1. Nonverbal Task of Spatial Reasoning

A computer game was developed in which children had to remember which side of line (*above, below, right* or *left*) a dot appeared inside a circle.

Stimuli could appear in one of 16 spots on the screen (Fig. 1).

Each relation appeared in each position on the screen resulting in 48 unique trials over span of about 5 minutes (Fig. 2).

Feedback was provided to the child after each trial.

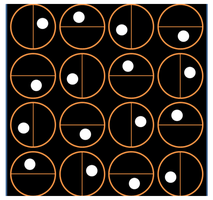
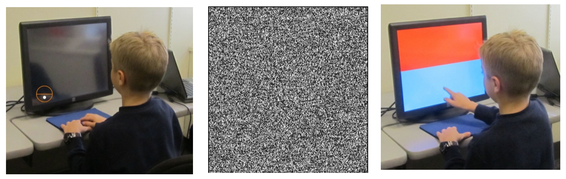


Fig. 1: (left), Possible locations of stimuli. Each relation appeared in each quadrant an equal number of times.

Fig. 2: (below), A sample trial of the "below" query.



2. Verbal Tasks of Spatial Reasoning

Production task : Each child was asked to say where the magnet was with respect to the circle (Fig. 3a).

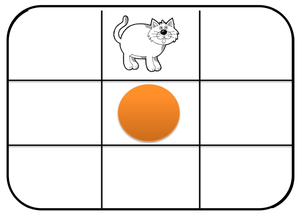


Fig. 3a: A sample trial of the production task: "Where is the cat?" Correct answer: "above" the circle.

Comprehension task: child told where to place the magnet with respect to the circle (Fig. 3b).

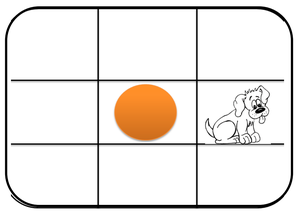


Fig. 3b: A sample trial of the comprehension task: "Put the dog to the right of the circle." Correct answer: child places the dog to the *right* of the circle on the board.

Order of reference objects was consistent throughout testing: in the following order: cat, dog, house, & child.

The location of each reference object for each trial was randomized using a Latin square design.

Each reference object was presented in each of the four possible relations four times for a total of 16 trials in each verbal task.

RESULTS

Preliminary evidence showing percent correct responses on each trial for each relation as a function of age appear in Figures 4 & 5. We found a main effect of age on each task (ANOVA).

We also found a significant difference between *right/ left* and *above/ below* in the verbal task, and in the nonverbal task only between the relations of *above/below* and *right* for 7 year olds.

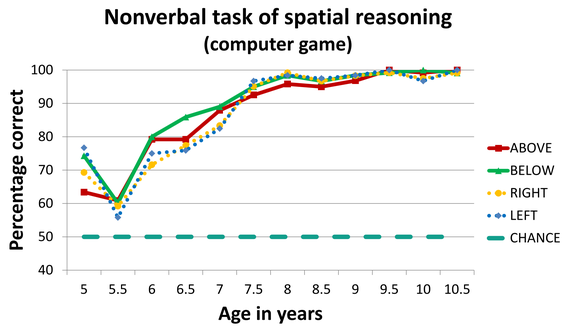
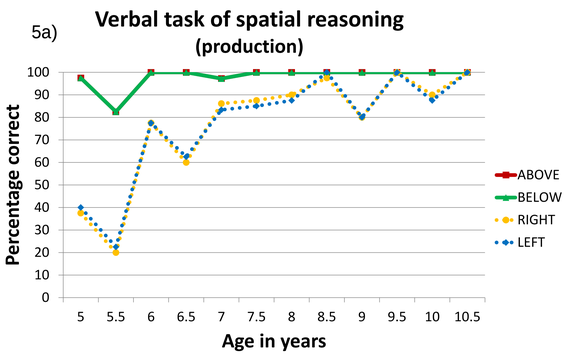


Fig. 4: Evidence of improving performance with increasing age for all relations on the nonverbal task. An examination of effect sizes suggests an advantage for extracting *above* or *below* relations over *right* or *left* relations between 6 and 7 years of age (Cohen's d ranges from .385 to .762 on pairwise t-tests).



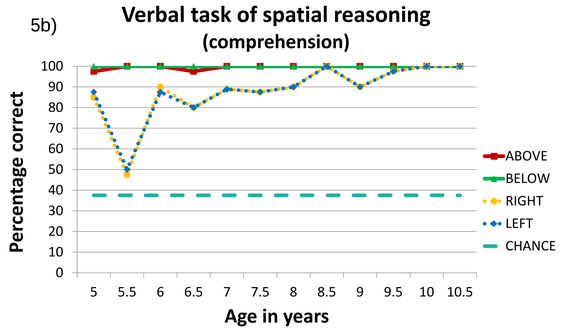


Fig. 5a,b: On the verbal task, children performed at ceiling on 'above' and 'below' but 'right' and 'left' show improvement with age, especially on the production task.

CONCLUSION AND FUTURE DIRECTIONS

Our evidence to date is most consistent with the idea that the same underlying mechanisms are at play in the ability to extract the spatial relations *above, below, right* and *left* in a nonverbal task by humans.

Although we found that knowledge of the words *above* and *below* precedes the ability to accurately extract the relations in a nonverbal task, strong evidence for the idea that the ability to extract the relations is linked to language should have yielded better performance in the nonverbal task for *above* and *below* in comparison to *right* and *left*, and the evidence for such an effect is weak since only 7 year olds show a difference and they only show it for *right* but not *left*.

However, these findings could indicate that language plays a role in accurately extracting spatial relations at a time point in development that is critical in learning the terms *right/left*.

The effect sizes also suggest that we may not have tested enough children, especially between the ages of 6 and 7 years, to obtain reliable differences.

In future analyses, we will examine whether the asymmetries in linguistic performance affect the speed with which the relations are extracted.

We may also examine whether language affects the length of time that the relations are remembered because past work suggests that language's effects are most apparent when longer times are required between relational coding and a behavioral response (e.g, Hermer and Spelke, 1996).

In the next part of this project, we will explore the neural mechanisms involved in making these spatial relational decisions by adults in the nonverbal task while recording neural activity using MEG.

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