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Brief Report

# The relation between spatial thinking and proportional reasoning in preschoolers

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ABSTRACT

Previous research has indicated a close link between spatial and mathematical thinking. However, what shared processes account for this link? In this study, we focused on the spatial skill of map reading and the mathematical skill of proportional reasoning and investigated whether scaling, or the ability to relate information in different-sized representations, is a shared process. Scaling was experimentally manipulated in both tasks. In the map task, 4- and 5-year-olds ($N = 50$) were asked to point to the same position shown on a map in a larger referent space on a touch screen. The sizes of the maps were varied systematically, such that some trials required scaling and some did not (i.e., the map had the same size as the referent space). In the proportional reasoning task, children were presented with different relative amounts of juice and water and were asked to estimate each mixture on a rating scale. Again, some trials required scaling, but others could be solved by directly mapping the proportional components onto the rating scale. Children's absolute errors in locating targets in the map task were closely related to their performance in the proportional reasoning task even after controlling for age and verbal intelligence. Crucially, this was only true for trials that required scaling, whereas performance on nonscaled trials was not related. These results shed light on the mechanisms involved in the close connection between spatial and mathematical thinking early in life.



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## Introduction

Previous studies have indicated that spatial and mathematical reasoning are closely linked (e.g., Hegarty & Kozhevnikov, 1999; Reuhkala, 2001; for a review, see Mix & Cheng, 2012). However, it is largely unknown what shared processes account for this relation. One potential link connecting certain types of spatial and mathematical reasoning may involve scaling—the ability to map different-sized representations onto each other by mentally transforming their extent.

Many spatial tasks involve scaling. For instance, navigation often requires relating distance information on a map to a larger space. Mathematical tasks such as proportional reasoning also require understanding that different proportions can have the same value (e.g., 1/3 = 2/6; Boyer & Levine, 2012). Consequently, understanding how different-sized magnitudes relate to each other might account for some commonalities between particular spatial and mathematical skills. The current study aimed to investigate (a) whether preschoolers' spatial localization skills and proportional reasoning are related and (b) whether this relation differs when scaling is or is not required.

Studies investigating children's map use in spatial search tasks have shown that preschoolers have great difficulties (Liben & Yekel, 1996), and their accuracy to locate targets develops considerably (Frick & Newcombe, 2012; Vasilyeva & Huttenlocher, 2004). However, if task requirements are low, even 3-year-olds succeed in using metric information from small-scale maps (Huttenlocher, Newcombe, & Vasilyeva, 1999). Children and adults seem to solve such tasks by mentally transforming spatial information presented on maps to the size of the referent space (Möhring, Newcombe, & Frick, 2014), as indicated by linear increases in response times and errors with larger scaling factors. Such linear response time patterns have typically been taken as indicators of mental transformation strategies in mental imagery research (Kosslyn, 1975; Shepard & Metzler, 1971).

Studies on the development of early proportional reasoning show heterogeneous results. On the one hand, 5-year-olds can successfully rate probabilities of events on a continuous scale (Schlottmann, 2001), and 3- and 4-year-olds can match proportions across substances (e.g., half a pizza equals half a chocolate bar; Singer-Freeman & Goswami, 2001). On the other hand, same-aged children had difficulties in finding the matching proportion between two alternatives (Boyer & Levine, 2012; Spinillo & Bryant, 1991). These studies suggest early proportional reasoning abilities; however, this ability is not fully developed, and individual variance is still large. Therefore, preschool age may be ideal to investigate the relationship between proportional and spatial reasoning because individual variance in both abilities should be large and shared variance can be optimally detected.

The proportional reasoning task in the current study presented continuous amounts of cherry juice and water based on findings that children are more successful when reasoning about proportions presented with continuous amounts as opposed to discrete amounts that may elicit counting strategies (Boyer, Levine, & Huttenlocher, 2008; Spinillo & Bryant, 1999). Other studies showed that children succeed earlier when using a rating procedure with a continuous response scale (Schlottmann, 2001). Thus, children in the current task were asked to indicate the cherry taste of different mixtures on a rating scale. Importantly, the design involved trials that required scaling and trials in which the proportional components could be mapped directly onto the rating scale.

Preschoolers' spatial localization was measured in a search task using a touch screen. Children saw maps showing a target and were asked to point to the same location in a larger referent space. Again, the ratio between the size of the maps and the referent was varied systematically, such that some trials required scaling and some did not (i.e., maps had the same size as the referent space).

We expected a significant correlation between children's proportional reasoning and spatial localizations. In addition, if scaling is an underlying process, we expected a relation only for scaled trials but not for nonscaled trials. Furthermore, based on literature on mental imagery and spatial scaling (Kosslyn, 1975; Möhring et al., 2014; Shepard & Metzler, 1971), response times and errors in both tasks were expected to increase linearly with increasing scaling factors if children used a mental transformation strategy. Finally, to control for the possibility that the current findings were due to general differences in intelligence, a subgroup of children completed an additional task that assessed verbal skills.