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Development of mental rotation in 3- to 5-year-old children

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ABSTRACT

We assessed 3- to 5-year-olds' mental rotation abilities using a new puzzle paradigm. It allows for assessment of mental rotation abilities in children younger than 5 years, using a task comparable to ones used with older children and adults. Children saw pairs of asymmetrical ghost figures, either as three-dimensional cut-outs or two-dimensional paper versions, in seven orientations. One of the ghosts fit into a hole if rotated right-side up – the other ghost was its mirror image and would not fit. Children were asked to turn the ghosts in their heads and choose the one that would fit into the hole. The number of children who chose the correct ghost above chance in the three-dimensional version of the task increased dramatically from 10% of 3-year-olds to 95% of 5-year-olds; average accuracy also increased significantly, from 54% to 83%. The two-dimensional paper version yielded similar results. These results indicate considerable development in mental rotation between 3 and 5 years.

Mental rotation is the ability to imagine how an object would look in a different orientation – in other words, to turn something in one's mind. Mental rotation tests often are used as measures of spatial visualization abilities and mental imagery processes in general. Factor analytic research has shown that visualization is a well-defined component skill within general intelligence in adults (Carroll, 1993), and spatial visualization abilities have been shown to play an important role in achieving

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advanced degrees in academic disciplines such as science, technology, engineering, and mathematics (Wai, Lubinski, & Benbow, 2009). A number of studies have suggested that children can perform mental rotations by the age of 5 years, although at a slower speed than adults (Frick, Daum, Walser, & Mast, 2009; Funk, Brugger, & Wilkening, 2005; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Marmor, 1975).

Research on the development of mental rotation in children younger than 5 years is challenging, however, because classic mental rotation paradigms used with adults and older children present high cognitive demands that may exceed young children's capacities. For example, in work by Shepard and Metzler (1971) and Marmor (1975), participants saw two objects that were either exactly the same or mirror images of each other – one oriented upright and one rotated. The participants' task was to pull one of two levers to indicate whether the objects were the same or different. To succeed in this task, children have to understand what constitutes a "same" or "different" object, remember which lever stands for which response, generate a mental image of the object, and maintain this image while performing a mental transformation on it. Even discriminating non-rotated mirror images in a same-different task poses significant demands on kindergartners (Cronin, 1967).

Given the cognitive complexity of same-different judgments, it is not surprising how rarely a mental rotation task using this response mode has been successfully presented to children younger than 5 years, and how inconsistent the findings have been. Marmor (1977) presented two pictures that differed in angular orientation and asked 4- and 5-year-olds to press a lever on the left when they saw matching-image pairs of stimuli (e.g., bears) or a lever on the right when they saw mirror-image pairs. Marmor argued that her data showed that 4-year-olds were already able to perform mental rotation. However, a follow-up study (Dean & Harvey, 1979) that employed the same procedure with slightly different stimuli failed to replicate Marmor's results and showed that 4- to 6-year-olds performed at chance levels. Marmor also found that training children to use a mental rotation strategy did not have a significant effect, suggesting that they already showed robust skill. However, a later replication study (Platt & Cohen, 1981) showed that twice as many 5-year-olds given training produced response patterns indicative of mental rotation, compared to children without training. Indeed, even though widely accepted at the time, there has always been some controversy about the conclusions from Marmor's studies (Newcombe, 2002). For instance, research that focused on individual children's response patterns revealed that only a small proportion of 4-year-olds showed a pattern consistent with mental rotation (Estes, 1998). Taken together, these mental rotation studies have yielded inconsistent results that cast some doubt on the idea of robust mental rotation in preschool children. Moreover, some of these studies suggest that many children still perform poorly on mental rotation tasks at 4–5 years of age and indicate that there are important individual differences in mental rotation abilities at this age.

On the other hand, mental rotation has been studied recently in infants and toddlers using paradigms not involving explicit judgment. Using looking-time paradigms, infants seem able to distinguish between objects and their rotated mirror objects (Frick & Möhring, 2013; Möhring & Frick, 2013; Moore & Johnson, 2008, 2011; Quinn & Liben, 2008; Schwarzer, Freitag, Buckel, & Lofruthe, 2012) or between probable and physically improbable rotation events (Frick & Wang, 2013; Hespos & Rochat, 1997; Rochat & Hespos, 1996). Moreover, in a task using physically available objects and a clear goal, 22-month-olds can rotate objects and successfully fit them through holes (Örnkloo & von Hofsten, 2007), although this ability improves considerably across the age range from 15 to 30 months (Shutts, Örnkloo, von Hofsten, Keen, & Spelke, 2009). These indications of early understanding of rotation events bring into question whether the reports of relatively poor performance among preschool children reflect their actual mental rotation competence or are merely a result of high task demands.

Previous mental rotation studies have also yielded inconsistent results with regards to the question of sex differences. Sex differences are frequently reported in studies on mental rotation in adults, as shown by two meta-analyses (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995). However, Linn and Petersen's meta-analysis did not include children younger than 10 years old. The more recent meta-analysis by Voyer et al. listed four studies of mental rotation with children below the age of 10, three of which found no significant sex effects (Caldwell & Hall, 1970; Jahoda, 1979; Kaess, 1971). Interestingly, Voyer et al. found a positive relation between chronological age and effect size, suggesting that sex differences increase with age. If so, an important question becomes when sex differences begin to