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Non-symbolic division in childhood

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ABSTRACT

The approximate number system (ANS) underlies representations of large numbers of objects as well as the additive, subtractive, and multiplicative relationships between them. In this set of studies, 5- and 6-year-old children were shown a series of video-based events that conveyed a transformation of a large number of objects into one-half or one-quarter of the original number. Children were able to estimate correctly the outcomes to these halving and quartering problems, and they based their responses on scaling by number, not on continuous quantities or guessing strategies. Children's performance exhibited the ratio signature of the ANS. Moreover, children performed above chance on relatively early trials, suggesting that this scaling operation is easily conveyed and readily performed. The results support the existence of a flexible and substantially untrained capacity to scale numerical amounts.

Introduction

Psychologists who study the development of proportional reasoning have long detailed the difficulty that young children have in understanding symbolic ratios, fractions, and division (Carpenter, Corbitt, Kepner, Lindquist, & Reys, 1981; Dixon & Moore, 1996; Fischbein, 1990; Kieren, 1988; Mack, 1990; Moore, Dixon, & Haines, 1991; Nunes, Schliemann, & Carraher, 1993; Piaget & Inhelder, 1956, 1975; Post, 1981; Reyna & Brainerd, 1994; Singer, Kohn, & Resnick, 1997). The part–whole relationship, a key component of proportional reasoning, can be particularly difficult to master

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in numerical contexts; in one classic study, children up to 7 years of age struggled to understand that an array comprising six roses and two daisies has more flowers than roses (Inhelder & Piaget, 1964). In addition, the inverse relationship between the number of partitions of a set of objects and the number of objects in each partition is challenging for young children (Frydman & Bryant, 1988; Sophian, Garyantes, & Chang, 1997; Spinillo & Bryant, 1991). In one study, 5-to 7-year-olds were presented with a number of "pizza bits" to distribute among multiple sharers with the goal of obtaining the largest share of bits for a "pizza monster" (Sophian et al., 1997). Children had difficulty in realizing that the more portions into which the bits were divided, the fewer the bits in each portion. Finally, preschoolers who see a set of objects divided in half, and who are provided with the number of objects in one of the halves, are unable to infer that the other half has the same number of objects (Frydman & Bryant, 1988). All of these findings suggest that young children fail to grasp the logic of exact division of discrete quantities.

In contrast, a further body of work reveals that young children competently reason about proportions and ratios in tasks presenting continuous quantities such as overall area or space (Duffy, Huttenlocher, & Levine, 2005; Goswami, 1989; Jeong, Levine, & Huttenlocher, 2007; Mix, Levine, & Huttenlocher, 1999; Sophian, 2000; Spinillo & Bryant, 1991; but cf. Piaget & Inhelder, 1956). In one such study, Goswami (1989) found that by 6 years of age children who were given multiple examples of a particular proportion of shaded/unshaded area in a shape were able to pick a test item that showed the same proportion. In a similar paradigm, Sophian (2000) presented 4- and 5-year-olds with a sample stimulus that exhibited a particular proportional relationship (e.g., an animal with a relatively small body and large head) and asked them to choose the animal that was "just like" it from a pair of test items, one of which presented the same proportional relationship. Children successfully performed this analogical task at as young as 4 years across a range of stimulus types and configurations.

There is also suggestive evidence for a special sensitivity to halving within the context of analogical proportion reasoning, with the concept of "half as much" being privileged in the mind of a child. Spinillo and Bryant (1991) presented children with a box that exhibited a particular proportion of one color to another (e.g., 3/8 blue and 5/8 white) along with two pictures and asked children to choose which picture matched the correct proportion exhibited by the box. By 6 years of age, children were significantly better at choosing the matching picture when the foil crossed the half boundary (i.e., 3/8 vs. 5/8) than when it did not (i.e., 3/8 vs. 1/8). They also performed better overall when given a standard stimulus that exhibited an exact one-half proportion. The authors proposed that one-half acts as a category boundary to proportional reasoning. These results, together with other studies that show an early facility with simple proportions that are readily relatable to a proportion of one-half (Ball, 1993; Goswami, 1989; Mix et al., 1999; Singer-Freeman & Goswami, 2001), suggest that the process of mentally halving a continuous amount might be special capacity of limited flexibility.

With few exceptions (e.g., McCrink & Wynn, 2007), young children's successful proportional reasoning has been observed only with non-numerical spatial quantities. Indeed, children seem to be actively impaired in proportional reasoning about precise numbers (Boyer, Levine, & Huttenlocher, 2008; Jeong et al., 2007; Singer-Freeman & Goswami, 2001; Spinillo & Bryant, 1991). For example, Boyer and colleagues (2008) provided first- and third-graders with a standard that exemplified a particular proportion (e.g., a beaker one-third full of juice) and instructed them to choose from a pair of test stimuli the picture that was the "right mix" of juice. Children were able to perform the task readily when the choice was over a continuous amount of liquid, but when the standard was notched into countable units of juice and water even older children failed to intuit and apply the correct relationship between the standard and test items. Dissociations such as these have led some theorists to posit that the strategies children use to reason about number, such as counting, interfere with intuitive notions of proportion (Gelman, Cohen, & Hartnett, 1989; Mix et al., 1999).

A parallel body of literature has established that human adults, children, infants, and non-human animals are able to represent large numbers of objects (Cordes, Gelman, Gallistel, & Whalen, 2001; Gallistel, 1990; Starkey & Cooper, 1980; Starkey, Spelke, & Gelman, 1990; van Loesbrook & Smitsman, 1990; Xu & Spelke, 2000), events (Platt & Johnson, 1971; Wood & Spelke, 2005), and sounds (Lipton & Spelke, 2004; Meck & Church, 1983) in an approximate fashion. The approximate