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Learning to solve figural matrix analogies: The paths children take

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A B S T R A C T

Analogical reasoning is essential for acquiring and integrating new knowledge and skills. Although much research has focused on this important skill, children's paths from non-analogical to analogical reasoning remain unclear. In this study, 388 children (ages 4–10 years) solved a series of figural analogies within a pretest-training-posttest design, with training comprising either multiple tries ($N = 196$) or tutoring feedback ($N = 192$). Working memory tasks were also administered. Latent transition analyses identified five phases with qualitative individual differences in children's analogy solving: duplication, idiosyncratic, beginner analogical, intermediate analogical and advanced analogical reasoning. Children's paths through these phases were not sequential; there was great variability between children and how they progressed through these phases. Working memory was related to children's reasoning phase at pretest, but not to their rate and path of change. Age and the type of feedback received during training were the clearest indicators of children's learning paths and rates of change.

1. Introduction

Analogical reasoning, the ability to recognize and use similarities and to generalize information from known situations to new ones, is essential for acquiring and integrating new knowledge and skills (Alexander, Jablansky, Singer, & Dumas, 2016). Children from a young age appear capable of reasoning by analogy (Goswami & Brown, 1990b; Rattermann & Gentner, 1998). However, factors such as lack of relational knowledge (Goswami, 1991), limited ability to shift focus from associative or perceptual features to relational features (Gentner, 1988; Hosenfeld, van der Maas, & van den Boom, 1997; Sternberg & Rifkin, 1979), and limited processing capacity (Halford, Wilson, & Phillips, 1998; Richland, Morrison, & Holyoak, 2006) form bottlenecks in its application. We know that children use a variety of approaches when learning to solve figural analogies and the most prominent approach prior to complete analogical reasoning is duplication, in which a copy of one of the problem elements is given as the solution (Siegler & Svetina, 2002; Tunteler, Pronk, & Resing, 2008). However, it is unclear *which* children transition *when* and *how* from being unable to correctly solve analogies to mastering analogical reasoning. The goal of this study was to shed light on individual learning phases and paths in the acquisition of figural analogical reasoning. In order to achieve this, we used dynamic testing, a microgenetic method of assessing cognitive ability and potential by including training in the assessment process, to observe and accelerate development (Elliott, Grigorenko, & Resing, 2010).

Analogical reasoning development is often examined with classical figural analogy tasks (see Fig. 1 for an example). The problem structure is usually described as A:B::C:?, where A-C represent subsequent problem elements (e.g., in Fig. 1, A is the figure with two small blue elements, B is the yellow elephant, C is the picture of two blue horses and the ? is the empty box that needs to be solved). Usually multiple-choice items are used (e.g., Chen et al., 2016; Siegler & Svetina, 2002). In the current study we used a constructed-response format which does not overly limit the children's solution choices and thereby provides a better picture of how they solve analogies (Stevenson, Heiser, & Resing, 2016). Constructed-response figural analogies can be solved by first *encoding* the objects on relevant dimensions (e.g., "two small blue elephants facing left"), then *integrating* the similarities and differences on these dimensions for each of the problem elements (e.g., "one of the elephants has gone away, it changed color, and looks the other way"), and finally *mapping* the pattern of changes in these dimensions (both horizontal and vertical) to mentally and physically construct the solution to the problem (Chen et al., 2016; Sternberg & Rifkin, 1979).

In order to successfully complete the first two steps in analogy solving, encoding and inference, children must be familiar with the problem elements and the relations between them (Goswami, 1989, 1991). Children as young as 4-years-old can solve figural analogies, choosing relational similarities above associative or perceptual similarities, when they are familiar with the causal relations in the problem domain (Goswami & Brown, 1990a). However, when solving figural

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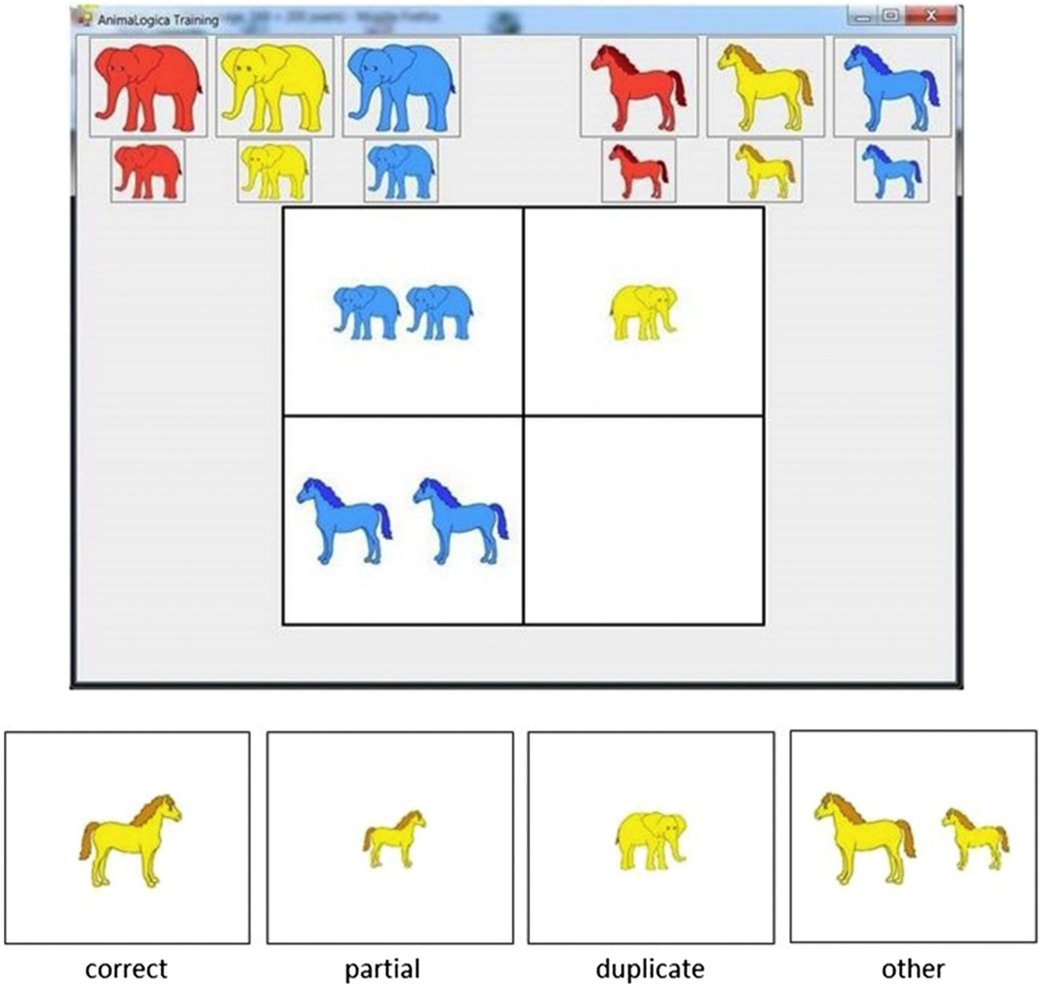

Fig. 1. A screenshot of a figural matrix analogy from AnimaLogica (Stevenson, Hickendorff, et al., 2013). Note that the solutions at the bottom are not multiple-choice options but, four examples of different types of solutions children provided.

analogies younger children generally choose duplicate solutions (i.e., copy of one of the matrix elements), a response based on perceptual rather than relational similarity. Siegler and Svetina (2002) attributed this to difficulty in encoding the relations required to solve the matrix. However, more recent studies in which children receive specific feedback on the relevant relations show that 5–6 year-olds are capable of encoding and representing these relations, and can become quite successful in solving figural analogies after just a few training sessions (Chen et al., 2016; Resing, Bakker, Pronk, & Elliott, 2017; Siegler & Svetina, 2002; Stevenson, Hickendorff, Resing, Heiser, & de Boeck, 2013; Tzuriel & Klein, 1985). Gentner (1988) proposed that a "relational shift" takes place in analogical reasoning where children's representations of relations between analogy elements shift from simple feature comparisons (e.g., 'This elephant is bigger than that one.') to more abstract relational structures (e.g., 'The elephants differ in size.') and that this "relational shift", rather than purely a question of age, steers the development of analogical reasoning (Gentner, Rattermann, Markman, & Kotovsky, 1995).

Improved executive functions, particularly working memory and inhibition control, is also considered a fulcrum for the transition from non-analogical to analogical reasoning in children (Halford et al., 1998; Morrison, Doumas, & Richland, 2011; Ropovik et al., 2016; Thibaut & French, 2016). Thibaut and French (2016) argue that young children have difficulty temporarily inhibiting the initial goal of the task 'Find the figure that goes with C [in the same way as A goes to B]' based on their research on the development of semantic analogy solving. This may also explain why children solve figural analogies with duplicates of C, although this is dependent upon instruction. Richland et al. (2006) argue that young children have difficulty inhibiting perceptual similarities and therefore choose perceptual distractors above relational solutions. This account is less dependent upon instruction and could explain why children choose a duplicate in multiple-choice items. Less clear is how children respond to constructed-response items, where duplicates must be constructed rather than uninhibitedly chosen.

The last step in analogical reasoning, where relational similarities between two of the figures are mapped onto the remaining figure to construct the solution (i.e., the mapping and solving step), is considered very taxing for working memory as the mentally constructed solution must be retained in memory while selecting or constructing figures to answer the problem (Chen et al., 2016; Grossnickle, Dumas, Alexander, & Baggetta, 2016; Sternberg & Rifkin, 1979). The processing capacity perspective easily explains why many children solve figural analogies with a partially correct solution – where although most changes from the A to B term are correctly mapped to the solution, one or two are "forgotten". Furthermore, a plethora of studies have shown that children's working memory capacity and analogical reasoning ability are strongly related (e.g., Engel de Abreu, Conway, & Gathercole, 2010; Hornung, Brunner, Reuter, & Martin, 2011; Kail, 2007). However, an open question is whether working memory is related to children's progression when learning to solve figural analogies, i.e., whether it can predict which children will transition from non-analogical strategies to full analogical reasoning. Some microgenetic, longitudinal and dynamic