Explaining children's failure in analogy making tasks: A problem of focus of attention?

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Abstract

Analogical reasoning is commonly recognized as essential to human cognition, but young children often perform poorly in the classical A:B::C:? analogical reasoning task. Previous eye-tracking results have shown that children did not visually explore the A:B pair as much as adults in this task. We hypothesized that this lack of exploration could help account for the low scores of children in comparison to adults. The present study shows that children' performance improves significantly if they are required to look at and process the A:B pair before they are shown the full A:B::C:? problem. This confirms our hypothesis that the A:B pair is insufficiently processed by children during the resolution of such problems.

Keywords: Analogical reasoning; development; executive functions; cognition.

Introduction

Analogical reasoning is a central feature of human cognition (Gentner & Holyoak, 1997; Hofstadter, 2001). It is defined as the transfer of a structured set of relations from a source domain to a target domain from which it is more or less distant. A most classical example is the A:B::C:D analogy (e.g., dog:doghouse::bird: ? solution "Nest", in which the "lives in" relation must be abstracted). In other analogy problems, a solution to a source problem can be used to solve a target problem (e.g. Holyoak et al. 1984).

Many experiments have been devoted to the study of ontogenetic changes in the ability of analogical reasoning (Chen, Sanchez, & Campbell, 1997; Gentner, 1988; Goswami & Brown, 1990; Holyoak, Junn, & Billman, 1984; Richland, Morrison, & Holyoak, 2006; Thibaut, French, & Vezneva, 2010a). Data suggest that analogical reasoning can be found present as early as 10 months in very simple experimental settings (e.g., Chen et al, 1997). Children's analogical reasoning capacities improve as their knowledge of the involved relations, or their abilities to resist irrelevant information increase. Several models have been proposed in order to explain these changes. They fall roughly into two subclasses: models that try to explain development of analogical reasoning by the increase of structured knowledge about the world (Goswami, 1992) and models that suggest that the key lies with the maturation of control processes, such as working memory or executive functions (Halford, Wilson, & Phillips, 1998; Richland et al., 2006).

Richland et al. (2006) and Thibaut and colleagues (Thibaut, French, & Vezneva, 2009, 2010a, 2010b; Thibaut, French, Vezneva, Gérard, & Glady, 2011) posited that while knowledge of relations is necessary to do analogy making, executive functions are also involved in solving analogical problems. Thibaut et al. interpreted their results as showing that younger children's difficulties with analogy making arose because of insufficiently developed executive functions, specifically inhibition. In one experiment involving semantic A:B::C: ? analogies with four possible responses Thibaut, French, and Vezneva, (2010b) compared weak and strong analogies (i.e., analogies in which the items of the A:B and C:D pairs were weakly, or strongly, associated). Results revealed poorer results in weak (e.g., shirt:suitcase::toy:box) analogies than in strong ones, especially when the number of distractor items was high (i.e., three vs. one). Importantly, the authors controlled to ensure that the children knew the semantic relations within the pair (i.e., the semantic relations between A and B, and between C and D). Thus, children's failure to map the A:B pair on the potential C:D target pair could not be explained by a lack of knowledge. They showed that a greater number of distractors led to poorer performance in the case of weak analogies. They suggested that for strongly associated A:B and C:D item pairs, children were not interfered with by the semantic distractors. In contrast, when the problem involved weakly associated items, mapping the A:B pair onto the C:D pair requires more than simply accessing the obvious semantic dimensions of the items.

The authors characterized analogy-making as a search through a space of features and potential relations. The number of relations holding between any A:B pair is potentially large because, depending on the context, any number of different relations might be relevant (Chalmers, French, & Hofstadter, 1992; French, 1995; Hofstadter, 1995; Mitchell, 1993; Murphy & Medin, 1985; Thibaut, 1997). As mentioned above, the structure of the search space and the presence or absence of competing non-analogical solutions have an effect on the search, especially for young children, who have greater difficulty handling the cognitive load associated with a more elaborate search of the space of possible solutions.

The notion of "searching in a semantic space" was directly investigated in an eye-tracking study by Thibaut, French, Missault, Gérard, and Glady (2011; Thibaut & French, submitted). The authors started with the idea that the search space in an analogy task is dynamically created as the result of comparisons between the items that compose the analogy problem and this requires the integration of the various sources of information that are available during the task. They used an eye-tracker because cognitive monitoring is difficult to assess with the sole performance measures (i.e., error measures and reaction times) that are usually used in the literature (e.g., Rattermann & Gentner, 1998; Richland et al., 2006; Thibaut et al., 2010b). Eye-tracking allowed them to study precisely how the space of potential solutions was explored by both children and adults. The idea was to study what parts of the space were explored and exactly when that exploration took place. By manipulating various aspects of analogical problems of the A:B::C:D type, eye-tracking allowed them to probe the factors affecting the search of solution space.

Compared with adults, children obtained poorer results. There were also key differences between adults and children in the temporal organization of their respective search profiles. First, adults focused on the A and B pair at the beginning of the trial, paying less or no attention to C and to stimuli in the solution set. Later they focused on C and the Target, which they compared with the semantically related distractor. At the end of the trial, the Target was their sole focus of attention. By contrast, children organized their search around C on which they actively focused during the entire trial. At the very beginning of the trial they paid more attention to C and B. They began looking at the Target and the semantic distractor earlier than in the adults' case. Thus the main differences between children and adults were that children focused on B and C at the beginning of a trial, compared to A and B for adults, and that the Target and the semantic distractor were focused on earlier by children than by adults. The comparison between error trials and correct trials in the case of children revealed that errors were characterized by longer looking times on C and shorter looking times on A. Overall, the results showed that children organized their search around C and paid less attention to A and B when necessary.

This pattern of results suggests that one reason children might fail in analogy-making tasks is that they do not pay sufficient attention to A and B or do not include them in their search. Recall that the task explicitly requires "finding the item that goes with C". Thus, in order to successfully comply with the task, children have to focus on stimuli other than the ones which are highlighted by the instructions, i.e. the C item and the set of distractors. Specifically, they have to study A and B and integrate information from these items in their search for the "one that goes with C". The executive function framework predicts that children might find it hard to inhibit the search-for-the-one-that-goes-with-C goal in order, first, to study A and B, and, second to compare what they have discovered for this pair and to integrate it in their search for the Target item that goes with C.

This analysis led us to the central prediction of the present paper. We started with the general hypothesis that young children find it hard to follow the instructions, that is, to integrate A and B in their exploration of C and the solution set. In this context, if the way the analogy task is implemented forces them to study and interpret the A:B pair, then they should obtain better results than in the classical situation in which all the stimuli are introduced simultaneously.

Thus, in the present experiment, we compared two conditions, i.e., the Standard condition and an A:B-first condition. In the latter condition, children first saw the A:B pair alone and were asked to describe the relation holding between A and B before they were shown C and the solution set. We hypothesized that the A:B-first condition would force children to focus on this pair which would help them to integrate it in their search for the correct C:Target pair.

Experiment

The present study more directly tested the influence of A:B in children's analogy making. The reasoning was as follows. If children do not pay enough attention to A:B while making analogies, they should obtain better results with procedures requiring a preliminary treatment and interpretation of the A:B pair. Children were, first, presented the A:B pair alone. Then, they had to study it and explain the semantic relation holding between A and B, *before* they were presented with the other pictures. We predicted that, in this condition, children would have higher scores than children that would see all the stimuli composing a problem simultaneously. Indeed, as suggested by Thibaut, et al., (2011), young children have difficulties not looking at C and the solution set rather than at A and B. In a similar vein, Thibaut and French (submitted) showed that a distinctive feature of errors, compared to correct trials, is an imbalance between A and C in favor of C.

Methods

Participants

Subjects were 42 5-year-old preschool children (M = 67.1 months; range, 57 to 77 months). Their participation to the experiment was submitted to informed consent of their parents.

The subjects were equally divided into two groups: Standard Analogies group (N = 21; M = 67.4 months; range, 56-75 months) and A:B-first group (N = 21; M = 66.8 months; range, 59-77 months).

Materials

The experiment consisted of 14 trials, with 2 training trials and 12 experimental trials (See Table 1 for the list of trials). Analogies were of the A:B::C:? format composed of 7 items (black and white drawings; see Figure 1). The problem consisted of the A:B pair (the source), the C item (the target), and an empty square. The solution set was composed of four stimuli: the analogical answer, a distractor that was semantically related to the C item, and 2 items that were not semantically related to C. Positions of the different alternatives were counterbalanced.

The trials were presented to the children on a touch screen controlled by an E-Prime® program used to run the experiment.

Procedure

Children were individually tested in their school, in a quiet room.

First, participants' knowledge of the stimuli used in the experiment was assessed. Each stimulus was introduced alone and participants were asked to name it or, when they did not know its name, to describe its function or a context in which it could be found. Children recognized 98% of the items correctly. The analogy task followed.

The Standard Analogies group was shown all 7 items defining a problem simultaneously. In the first practice trial, the task was explained to children belonging to the Standard Analogies group as follows: "Let me explain how it works. At first, you have to find why these two pictures [showing A and B] go well together. So, why do you think [A] goes with [B]? OK! You see this one [showing C]? It is alone. What you have to do is to find one picture in these four images [showing the four answer options] that goes well with this one [C] in the same way as this one [B] goes with [A] so the two pairs of pictures go together for the same reason. Which picture goes up there [showing the empty slot] with [C] like [B] with [A]? The child gave an answer and justified her choice. Then, the experimenter rephrased the entire trial, explaining and emphasizing why "A and B" and "C and D" go together for the same reason. During the second practice trial, they were asked to do the same. When children did not attend to the A:B pair while explaining their choice, they were asked to do so, and care was taken to ensure that they understood the instructions during the training trials. In the experimental phase, they were asked to do the same thing that was explained to them during the experiment trials and to justify their answer afterward. No feedback was given for the experimental trials.

The A:B-first group was first shown the A:B pair alone and was asked to describe the semantic relation holding between the two drawings: "Why do these two things go together". Once they had given the relation, the

A	B	C	D (Target)	Semantic Distractor	Relation
Practice trials					
Wolf	Meat	Goat	Grass	Horns	*Eat*
Child	Foot	Elephant	Paw	Giraffe	*Part of*
Experiment trials					
Shirt	Suitcase	Toy car	Box	Gas pump	*Put in*
Child	Bed	Cat	Pillow	Whiskers	*Sleep on*
Pig	Dish	Man	Plate	Watch	*Eat in*
Man	Nose	Stag	Muzzle	Owl	*Breathe with*
Glass	Sideboard	Ring	Case	Watch	*Put in*
Pineapple	Bottle	Orange	Carafe	Strawberry	*Put juice in*
Train	Rails	Boat	Sea	Crab	*Move on*
Glove	Hand	Shoe	Foot	Footprints	*Put on*
Lamp	Socket	Remote control	Battery	Radio	*Work with*
Bird	Nest	Dog	Doghouse	Bone	*Live in*
Spider	Cobweb	Bee	Beehive	Flower	*Live in*
Lock	Key	Bottle	Corkscrew	Glass	*Open*

Table 1: List of stimuli and relations used to build the analogies of the experiment

experimenter displayed the full set of 7 stimuli defining the problem and asked them to complete the second pair as for the other group. Apart from this preliminary question for the A:B pair, the two practice trials were framed in the same way as in the Standard Analogies group. In other words, after they had mentioned the relationship holding between A and B they were shown the set of stimuli defining a trial and the same instructions as in the Standard Analogies group were given.

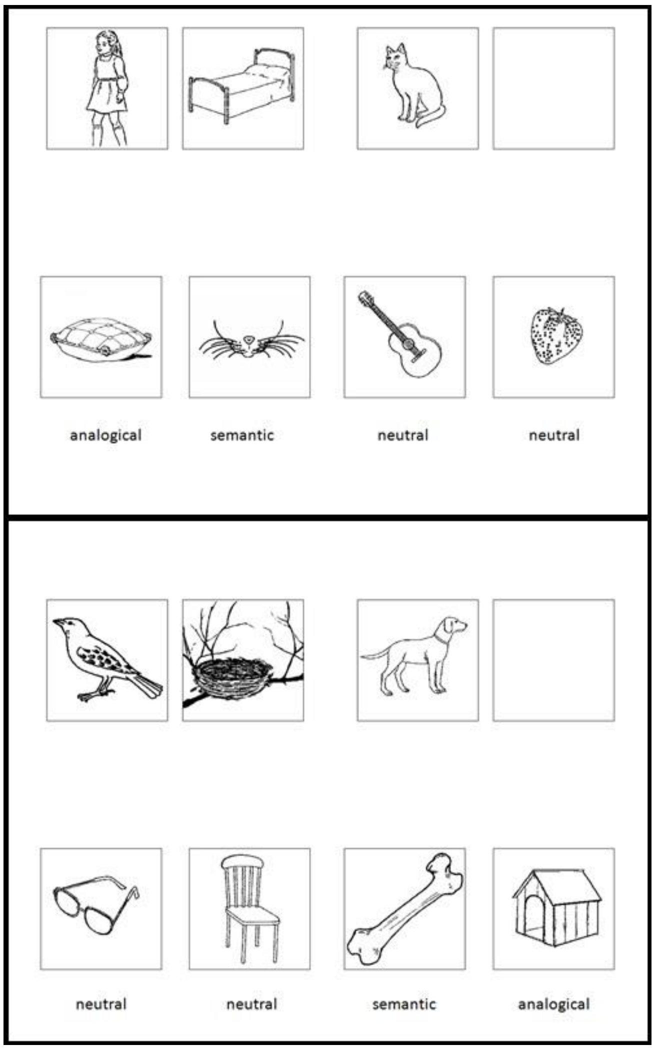

Figure 1: Two examples of analogies used in the experiment. Analogical: Analogical answer; Semantic: Distractor related to the C item; Neutral: unrelated picture

Afterwards, children's understanding of the semantic relation between A and B and between C and D was assessed. They were shown the A:B pairs and were asked *why* the two items of each pair went together. The same was true for the C:D pairs (see Thibaut et al., 2011, for more details).

Results

We first removed all the trials in which children could not identify one of the semantic relations, either A:B or C:D. As a result, 3% of the trials were removed from subsequent analysis. Note also that in most trials (90% of the cases), children found the target relation that was intended by the experimenter.

We ran a one-way ANOVA on the scores defined as the proportion of correct answers with Condition (Standard Analogies vs. A:B-first) as a between-subject factor.

There was a main effect of condition, $F(1, 40) = 6.02$, $p < .05$, $\eta^2 = .13$, with better scores in the A:B-first condition (mean score = .68; see Figure 2) than in the Standard Analogies condition (mean score = .58). These results confirmed our hypothesis that processing the A:B pair first could help children in their search for the analogical answer.

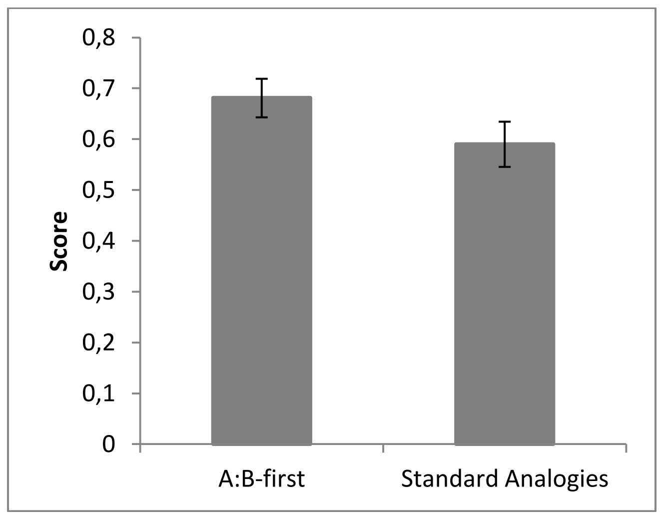

Figure 2: Scores of the 5-year-olds in the analogical reasoning test in the two conditions; $p < .05$.

When children did not select the analogical match, in 84.5% of the cases, they selected the distractor that was semantically related to C. This result differs significantly from chance (25% of selection, one-sample t test; $t(41) = 21.31$, $p < .001$).

General discussion

The main purpose of the experiment presented in this paper was to test whether young children's difficulties in analogy-making might result from their difficulties to integrate the A:B pair in the analogy problem. In this study, we conjectured that one source of children's difficulty lies in their search strategy for the task. We suggest that this strategy is, at least in part, induced by the instructions which require them to find “the item that goes with C.” In the experiment, we directly tested our hypothesis in a condition that required children to first interpret the A:B pair. It was compared with the classical analogy problems. The results confirmed our hypothesis, since children were better in the A:B-first condition.

The experiment is consistent with the idea that children spend less time than adults studying the A:B pair. These data are consistent with Thibaut et al. (2011) eye-tracking data (see also Thibaut & French, submitted) showing that children spend less time on A and B, compared to C, had fewer A:B transitions than adults. The experiment forced them to do what adults do spontaneously and, i.e., inducing the sequential A:B then C:D strategy, which gave rise to higher scores than in the “classical” simultaneous presentation.

Lovett et al. (2009) proposed a two-stage computational model of geometrical A:B::C:? task solving. The program’s performances fitted well with adults performances on Evans’ geometrical problems (Evans, 1968), predicting the different patterns of human answers on each item of the task. This program may also well model children’s pattern of answer observed in this study by modifying some of its processes, like allowing only a shallow first-stage A:B relational description that may result from the lack of treatment of this pair observed in children and/or not allowing the executive to induce another description of the A:B pair.

The increased performance in the A:B-first condition (Thibaut, French, Missault, et al., 2011) are entirely compatible with the executive function view. Given that the instructions prompt them to find a partner for C in the set of solutions, they might find it hard to inhibit the set of stimuli which were explicitly mentioned in the instructions. Another, related interpretation, could involve the representation and maintenance of the sub-goals of the task. This has been suggested for other tasks assessing executive functions (Blaye & Chevalier, 2011; Gruber & Goschke, 2004). Children may represent the main goal of the task, which is to find a picture that is related to the C item, but may have difficulty departing from this goal to achieve a crucial sub-goal – namely, finding which relation has to be used to find the correct answer between the different options related to the C item (analogical answer and distractor). Studying and verbalizing the relation linking the A:B pair may contribute to enhance this sub-goal. In this format, they should not have to generate this sub-goal by themselves. Another interpretation would be that children lack the correct strategy which is to look at the A-B pair first. In this context, our “A:B first” condition provided them with the correct strategy for performing the task. In other words, children would not know how to perform the task or to organize it in order to perform it correctly. This is a plausible hypothesis. However, it is difficult to disentangle what is due to inhibition and/or flexibility mechanisms from what results from an explicit strategy.

The studies in the literature have pointed out two main explanations of children’s failures to do analogies correctly. The first is the role of knowledge (e.g., Gentner, 1988; Goswami & Brown, 1990). The second is related to executive functions. It has been shown that children might have difficulties handling all the information available in the task, such as distractors related to C (see Richland et al., 2006; Thibaut et al., 2010a, b for discussions). The present research demonstrates that the task itself has cognitive constraints which generate a cognitive load that must be coped with by young children. In other words, for adults and most likely children older than 9, the comparison between A:B and C and the potential candidates for a solution is automatically driven by the task instructions (the so-called mapping process). By contrast, for children, temporally leaving aside the instructions “looking for the one that goes with C” in order to compare A with B, generates cognitive load. One might conceive of this as a necessity to temporarily inhibit C and the solution set, or as a necessity to be cognitively flexible, that is to be able to conceive the task under different perspectives (i.e., from an A-B perspective or from a C-solution set perspective and integrate these two perspectives). In sum, the present research has made it clear that the analogy task generates its own demands that cannot be taken for granted, in the case of children.

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