Generalizing relations during analogical problem solving in preschool children: does blocked or interleaved training improve performance?

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Abstract

Analogical reasoning, the mapping of structured relations across conceptual domains, is commonly recognized as essential to human cognition, but young children often perform poorly in the classical A:B::C:? analogical reasoning task. Particularly, young children have trouble when the objects in the task are not strongly associated with each other, and/or when there are strong associative lures among the potential answers. Here, we examine whether successive trials that repeat the same relation needed to solve the analogy can help overcome some of the challenges with weakly associated items. In the first of two experiments, our results were mixed. In the second, we simplified the design, and were able to more clearly show a benefit of repeating relations across consecutively solved problems.

Keywords: Analogical reasoning; development.

Introduction

Analogical reasoning lies at the core of human cognition (Holyoak, 2012; Hofstadter & Sander, 2013). It refers to the transfer of a structured set of relations from a source domain to a target domain, which can often generate insights into how to solve novel problems and generate new ideas (e.g., Gick & Holyoak, 1980; Lindsey, Wood & Markman, 2008). A typical way to research and assess analogical thinking ability is the A:B::C:D analogy (e.g., dog:doghouse::bird: ? solution "Nest", in which the "lives in" relation must be abstracted).

Many experiments have been devoted to the study of ontogenetic changes in analogical reasoning ability (Gentner, 1988; Holyoak, Junn, & Billman, 1984; Richland, Morrison, & Holyoak, 2006; Thibaut, French, & Vezneva, 2010b). Children's analogical reasoning capacities improve as their knowledge of the involved relations, or their abilities to resist irrelevant information increase (e.g., Goswami, 1992). 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 emphasizing the increase of structured knowledge about the world (Goswami, 1992) and models that emphasize the maturation of control processes, such as working memory or response inhibition (Halford, Wilson, & Phillips, 1998; Richland et al., 2006).

Richland et al. (2006) and Thibaut and colleagues (Thibaut, French, & Vezneva, 2008, 2010b; Thibaut, French, Vezneva, Gérard, & Glady, 2011) posited that while knowledge of relations is necessary for analogical reasoning, it is insufficient. They claimed that cognitive control processes are also critical for strategically inhibiting irrelevant information and responding consistently with the task main goal. Thibaut et al. interpreted their results as showing that younger children's difficulties with analogy making arose because of insufficiently developed control processes, 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 (French, 1995). 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 and French (2016; Thibaut, French, Missault, Gérard, & Glady, 2011). The authors 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).

In a A:B::C:D format, they found 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. By contrast, children devoted more time on C on which they actively focused during the entire trial and was used as an anchor stimulus, compared to A and B for adults, and that the Target and the semantic distractor were focused on earlier by children than by adults. These results suggest that children might fail in analogical reasoning tasks because they do not pay sufficient attention to A and B or do not include them in their search for the "one 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. However, as Thibaut et al (2010b) showed, strongly associated items constrain the search space sufficiently for children to readily map the relevant relation, with no ill effects of distractors. Here we examine whether presenting successive trials that require the same relation to solve the analogy will improves its use. That is, perhaps the semantic search does not need to start from scratch with weakly associated items if the relevant relation was still active in memory when the next item with the same relation is introduced. This account would predict that a *blocked* presentation of trials, which presents blocks of successive trial with same relation, would outperform an *interleaved* presentation format which would alternate between relations on successive trials (see Rohrer & Pashler, 2010). An advantage for blocked presentation would also be consistent with structural alignment accounts that emphasize that comparing pairs of objects bound by the same relation should help abstract that relation and generalize it to more disparate sets of objects because the process of comparison itself serves to shift attention to common relations and away from superficial differences between objects (Gentner, 2010). That is, multiple strongly associated pairs objects bound by the same relation should help children recognize when that relation applies to more weakly associated objects.

On the other hand, models of memory and discrimination learning predict benefits from interleaved presentation (Rohrer & Pashler, 2010). That is, spacing out instances of the same relation may elicit deeper processing each time it is retrieved, strengthening its memory compared to sequential presentations, which may reduce the attention paid to the repeated item (e.g., Greene, 1989). Additionally, spacing has been shown to aid not just memory, but generalization in young children (Vlach, Ankowsky, & Sandhofer, 2012) potentially because at each new instance, only the most relevant information is re-activated (i.e, the information common to both initial and later items), while irrelevant information is forgotten. Further, interleaving may build on the advantages of temporally spacing out examples by also filling in the temporal gaps with problems that rely on distinct structural relations. This interleaving of different relations can often aid learning and problem solving by setting up useful contrasts, sharpening the understanding of each relation.

In two experiments, we directly test the prediction that a blocked presentation will improve performance, shared by a semantic-search account and a structural-alignment account, against the prediction that interleaved presentation will improve performance, made by memory and discrimination learning accounts.

Experiment 1

In the first experiment, we aimed to test (1) whether accuracy using a relation improved over multiple trials wherein that specific relation solved the analogy (2) whether Weak trials specifically benefitted from following Strong trials and 3. whether these benefits depended on either a Blocked or Interleaved presentation.

Methods

Participants

Subjects were 47 4-5-year-old preschool children (M = 56 months; range, 49 to 64 months). Their participation to the experiment was submitted to informed consent of their parents.

The subjects were equally divided into two groups: Blocked group (N = 24; M = 55 months; range, 49-62 months) and Interleaved group (N = 23; M = 57 months; range, 50-64 months). Participants were randomly assigned to the blocked or the interleaved condition.

Materials

The experiment consisted of 2 practice trials, 12 learning trials and 4 posttest trials, which occurred with a minute delay after the learning trials. (See Table 1 for the list of trials). Analogies were of the A:B::C:? format and were composed of 7 items (colored pictures; see Figure 1). The problem consisted of the A:B pair (the source), the C item (the target), and an empty rectangle. The solution set was composed of four stimuli: the analogical answer, two distractors that were semantically related to the C item, and 1 distractor that was not semantically related to C. Positions of the different alternatives were counterbalanced across trials. There were two types of analogies, called "strong" and "weak". Strong and weak analogies were defined in terms of the semantic association strength within each pair of pictures defining an analogy, that is between A and B, and between C and the analogical target. It was determined by university students. They were asked to rate to what extent each item of the pair made them think of the other one. It was stressed that the task was to rate how strongly the two items were associated in their mind. The ratings were on a 1-to-7 scale. The strongly associated trials were composed of strongly associated A-B and C- T(arget) pairs, and the weakly associated trials were composed of weakly associated A-B and C-T(arget) pairs. The mean C-Target association strength was 3.53 (SD = 1.11) for the weak analogies, and 4.89 (SD = 1.44). for the strong.

In both learning conditions, there were 4 relations (tool for, produces, contains, becomes). For each relation, there were 3 learning trials, composed of 2 strong analogies and 1 weak analogy. In half of the trials, the two strong analogies were introduced before the weak trial whereas the reverse was true for the other half of trials. In the blocked condition, the three trials for one relation came in a row (either weak, strong 1, strong2, or strong1, strong2, weak, with two relations starting with a strong analogy and two relations with a weak analogy) whereas in the interleaved condition, each of the 4 relations was displayed once in a row, followed by another exemplar of the four relations. Two relations out of 4 started with a weak analogy and two relations by a strong. This was done in such a way that in both conditions the same "weak-strong-strong" or "strong-strong-weak" sequence were introduced for each relation. The 4 posttest trials were weak trials, one per relation. There were four versions of the blocked condition and four versions of the interleaved condition to counterbalance the order of the presentation of the relations, exemplars within the relations (e.g., which weak exemplar was in the post-test and which in the learning phase), which relations had strong exemplars first and which had weak.

The trials were presented to the children on a screen through a PowerPoint file.

Procedure

Children were individually tested in their school, in a quiet room. In both the blocked and the interleaved conditions, the 7 items defining one trial were displayed simultaneously. There were two practice trials. In the first practice trial, the task was explained to children 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. Which picture goes up there [showing the empty slot] with [C] like [B] with [A]? The child gave an answer and justified his/her choice. Then, the experimenter rephrased the entire trial, explaining and emphasizing why "A and B" and "C and Target" 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 relational learning 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 relational learning trials. The experiment was then interrupted for one minute. The experimenter and the child talked freely. Then, the four test trials, one per relation, were introduced as novel trials.

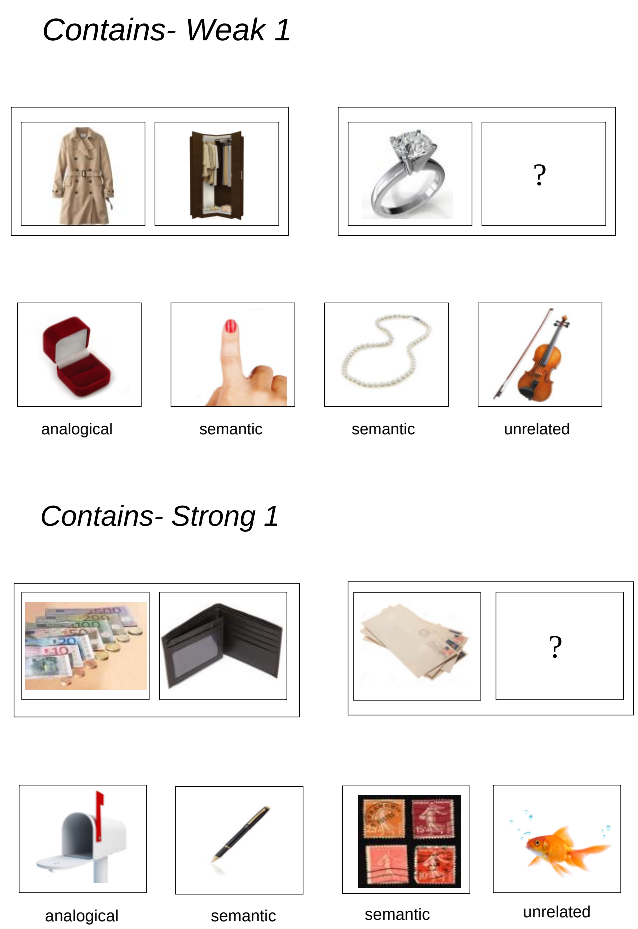

Figure 1: Two examples of analogies used for the "contains" relation, one "weak" and one "strong". Analogical: Analogical answer; Semantic: Distractor semantically related to the C item; Unrelated: distractor semantically unrelated to C.

At the end of the experiment, children's understanding of the semantic relation between A and B and between C and Target 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:Target 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 two semantic relations, either A:B or C:D. As a result, 49 trials out of 752 trials (the majority of them for "car producing exhausts) were removed from subsequent analysis. We first ran a two-way ANOVA on the proportions of correct answers for weak analogies with Position of weak (Before strong, After strong, At test) as a within factor and Presentation (Blocked, Interleaved) as a between-subject factor. It revealed a significant main effect of Position of weak, $F(2, 90) = 3.50$, $p < .05$, $\eta^2 = .07$. See Table 1. A Tukey HSD test revealed that the weak analogies were marginally significantly better understood when they were introduced after strong items rather before strong ($p = .056$) or at test ($p = .075$) with 24%, 39% and 25% of correct answers for the weak before the strong items, after the strong and at test, respectively. There was a decline for the weak items at test, which failed to reach significance, $p = .074$, compared to the second weak item). There was no main effect of Presentation and no interaction. A three-way ANOVA was conducted on the percentage of correct answers for strong stimuli, with Type of trials (Before weak, After weak), Position (First, Second strong) as within factors, and Presentation (Blocked, Interleaved) as a between factor. It revealed a main effect of Position, $F(1, 45) = 6.00$, $p < .05$, $\eta^2 = .12$), with the second strong higher than the first strong (M = 49% and 60%, for the first and second respectively). There was no main effect of Position and no significant effect of Presentation, and no interaction between any of the factors.

Table 1: E1 Means (SD's) for the proportion of accurate responses for each trial type

	Blocked	Interleaved
Strong 1	.49 (.22)	.49(.25)
Strong 2	.55(.26)	.65(.20)
Weak, before Strong	.27(.36)	.22(.29)
Weak, after Strong	.35(.40)	.43(.43)
Weak, after delay	.23(.21)	.27(.20)

Discussion

Results were mixed. On the one hand, for both Strong and Weak items, there were main effects of Position, suggesting that repeating relations improves performance. While the numerical increase of Weak trials following a Strong appears to be the root of the main effect of Position for those trials, post-hoc tests specifically looking at a benefit of a Weak trial following a Strong did not find a significant advantage contrasting it with either one of the other positions alone. In addition, there was no significant difference between a Blocked and an Interleaved mode of presentation, and not a significant effect specifically for Weak trials following Strong ones. Further, even after a delay of just one minute, there was quite low performance for weak items at test, perhaps due to that interruption. Indeed participants engaged in an informal discussion with the experimenter and this might have contributed to decrease their attention.

Experiment 2

Because of the mixed results, perhaps due to a lack of power, we simplified the design for the second experiment. First the teaching/test phase distinction was abolished. The same four relations were used with four trials each without any delay between trials. Another simplification was that the two strong analogies were always introduced before the weak analogies. The idea was to test whether weak analogies, that are more difficult than the strong analogies, would get more positive influence from strong analogies in the Blocked or in the Interleaved condition. The design of E1, with some Weak trials appearing after a delay and others before the Strong trials, may have prevented any potential benefit that a blocked presentation could provide. This simplified design will have a greater potential to detect any effect of Presentation. In addition, any effect of Presentation would show that experience with a specific relation improves performance over an above a general order effect which may simply reflect more general improvement at performing the task. The same hypotheses as in Experiment 1 apply here.

Methods

Participants

Subjects were 57 4-5-year-old preschool children (M = 55.4 months; range, 49 to 63 months). Their participation to the experiment was submitted to informed consent of their parents.

The subjects were equally divided into two groups: Blocked group (N = 29; M = 54 months; range, 49 to 62 months) and Interleaved group (N = 28; M = 56 months; range, 50 to 63 months). Participants were randomly assigned to the blocked or the interleaved condition.

Materials

The same set of analogies as in Experiment 1 was used, except for three pictures that were replaced in this novel version. In the two presentation conditions, the two strong analogies were always introduced before the two weak analogies. In the Blocked, the four analogies (trials) illustrating one relation (e;g., contains) were introduced before the four analogies depicting the next relation (e.g., tools for) were introduced. In each case, the two strong trials were introduced before the two weak trials. In the interleaved case, one strong analogy from each of the four relations were first introduced. It was followed by the second strong analogy of each of the fours relations which in turn was followed by the first and the second weak analogies. There were four versions of the blocked condition and four versions of the interleaved condition in which the order of presentation of the first and second strong, and of the first of second weak was modified.

Procedure

The same procedure as in Experiment 1 was used here, except that there was no test phase. The experiment started with two practice trials, and was followed by the 16 learning trials. There was no feedback in the learning trials.

Results

We ran a three-way ANOVA, with Presentation (Blocked, Interleaved) as a between factor, Analogy type (Strong, Weak), and Item Position (First, Second) as within subject factors. It revealed that strong analogies were significantly better understood than weak analogies (52 vs 30%), $F(1, 55) = 43.45$, $p < .0001$, $\eta^2 = .44$, and that the blocked presentation gave better results than the interleaved presentation, $F(1, 55) = 8.22$, $p < .01$, $\eta^2 = .13$ (M= 46% vs 36%). The key association strength x presentation interaction was also significant, $F(1, 55) = 4.22$, $p < .05$, $\eta^2 = .07$,showing that the difference between strong and weak analogies was larger in the interleaved case than in the blocked case. However, to examine effects on the Weak Trials specifically, we conducted a Presentation (Blocked, Interleaved) X Position (First, Second) mixed-effects ANOVA, which showed a main effect of Presentation, with Blocked (M = 38%) eliciting higher accuracy than Interleaved (M = 21%). $F(1, 55) = 12.24$, $p < .005$, $\eta^2 = .18$ (no other effects approached significance). See Figure 2.

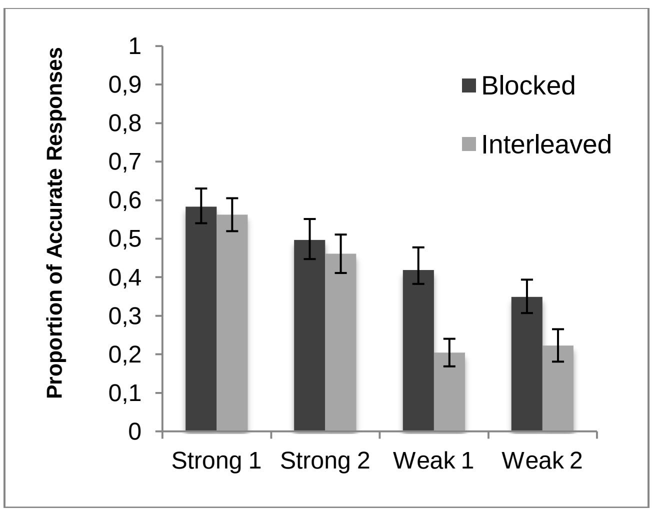

Figure 2: E2 Means and standard errors for proportion of accurate responses.

Discussion

Overall, the experiment showed that the Blocked condition led to better results than the Interleaved condition: seeing the four trials illustrating a given relation in a row led to better results than seeing the same relation in an interleaved way. Importantly, Presentation interacted with Association strength because the difference between Blocked and Interleaved conditions was concentrated in the Weak trials when analyzed alone. That is, examining Figure 2 clearly shows that Presentation order had little effect on the Strong trials, but did effect the Weak trials. When Weak trials directly followed Strong in the Blocked condition, this elicited more accurate use of the repeated relation.

Taking the two experiments together, a clear picture starts to emerge. Both experiments showed effects of the position of individual trials, generally supporting the idea that the use of a relation in one analogy problem can constrain the semantic search in a subsequent problem. The more simple design of E2 revealed an overall advantage of blocked presentation, supporting a semantic-search or structural alignment account, and suggests that the design of E1 was not sensitive to this advantage. In addition, while potentially an overall order effect could explain the effect of position in E1, in E2 the Blocked advantage is independent of an overall order effect, as the trials were matched in terms of the number of trials preceding them.

In Experiment 2, children in the blocked condition can first discover or build the relation using the two strong trials, then apply it to the following weak items that appear immediately after, without being interfered by the other relations. This limits memory decline between the strong and the weak trials. In the interleaved case, the larger decline between strong and weak items suggests that the interval between the weak and strong items was too important to allow a strong-to-weak generalization. Or the relations interfered one with the others.

While we showed preliminary support for the Blocked advantage further research is needed to confirm this advantage, and to clarify what kind of effects, if any, exists for sequence and presentation on Strong trials. For example, in E1 the second Strong trial was performed at a higher rate than the first, but during E2, it was the reverse! Both experiments were properly counter-balanced, so this difference is not due to item-differences. Additionally, if the Blocked advantage is further confirmed, then further research needs to test how blocking trials supports analogical problem solving. At the moment it is unclear whether this potential advantage is rooted in aiding the strategic retrieval of the relevant relational representation without changing that representation (as deficits in strategic semantic retrieval often explains poor reasoning performance in young children, Whitaker et al., 2017), or whether the successive trials allow for the children to abstract the relational commonalities, creating a representation less tied to the specifics of highly associated objects. Regardless, at this point, there is little evidence that the kinds of memory processes that specifically produce spaced and interleaved advantages in other domains seem to not play a crucial role in strengthening the use of relational representations in analogical problem solving. Interleaved schedules seem most helpful when the primary challenge concerns refining representations to aid discrimination. Our data suggests that this kind of “relational fine-tuning” or discriminating among similar relations is not a primary cause for children’s poor performance.

Here their effect, if any, was in favor of the Blocked trials. However, they may be crucial in helping to establish longer-lasting relational representations, given the post-test results from E1 showing the advantages from Blocked presentation may be quite short-lived. One way to test for lasting effects of the blocked presentation, would be to add the same set of weak trials at the end of the experiment and compare how participants behave in that case. A lasting difference between the two conditions in favor of the blocked trials would be strong argument in favor of this condition. Understanding how relational representations can be robust to temporal delays is a crucial direction for future research.

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