# Analogy-Making in Children: The Importance of Processing Constraints

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**Abstract**

The aim of the present study is to investigate children's performance in an analogy-making task involving competing perceptual and relational matches in terms of developmental changes in executive functioning. We hypothesize that the selection of the common relational structure requires the inhibition of more salient perceptual features (such as identical shapes or colors). Most of the results show that children's performance in analogy-making tasks would seem to depend crucially on the nature of the distractors. In addition, our results show that analogy-making performance depends on the nature of the dimensions involved in the relations (shape or color). Finally, in simple conditions, performance was adversely affected by the presence of irrelevant dimensions. These results are compatible with an analogy-making account (Richland et al., 2006) based on varying limitations in executive functioning at different ages.

**Keywords:** Analogy, analogy-making, development; processing constraints.

## Introduction

Analogy-making is, without question, one of the most singularly important ways in which children gradually make sense of their world. Certain authors (cf. Hofstadter, in Gentner, Holyoak, & Kokinov, 2000; French, 2007) have gone so far as to claim that it is *the* most important cognitive mechanism underlying development.

However, there is extensive work suggesting that analogy-making, in the sense of understanding and/or generating relations between objects or situations in the world, is a cognitive ability that develops only gradually (Gentner, 1988, etc.). It is well established that, while attribute-matching precedes relation-mapping in children, the preference for the latter occurs earlier or later depending on the child's familiarity with the domains involved (Gentner, 1988; Rattermann & Gentner, 1998; Goswami & Brown, 1990; etc.).

One of our goals is to disentangle two possibilities – namely, that, even in abstract domains consisting only of shapes and colors, young children might be *aware of* relational information between objects, but that, in contrast to older children, they *prefer* to use perceptual, attributional information in making their matching choices.

We do not contest the evidence that a preference for relation mapping comes to dominate perceptual-feature mapping as children grow older. We are simply suggesting that the ability to perceive and to map structures within and across domains depends on a *competition* between relational and attributional features of the domains. The outcome of this competition depends on the degree of salience of the competing relations and attributes. To our knowledge, the varying salience of attributes and relations and its effect on the types of children's matches (relational or attributional) has not been fully explored (see Richland, Morrison, & Holyoak, 2006).

Various views have been advanced to account for the developmental trend whereby as children grow older, they seem to prefer relational matching to attributional matching. A brief summary of these views follows.

Certain authors have emphasized the role of domain knowledge, suggesting that increasing knowledge about relations in one conceptual domain will increase analogy-making in the target domain (see Goswami & Brown, 1990; Vosniadou, 1995). According to Goswami (1992), analogical reasoning is already available in infancy. It is the lack of knowledge in one conceptual domain that prevents children from deriving the correct analogies.

Gentner (1988), Gentner & Rattermann (1991) and Rattermann & Gentner (1998) suggest that a so-called "relational shift" occurs in many domains during development, even though this shift does not occur at the same time for all domains. It is defined as a shift from early attention to common perceptual features to later attention to common relational structures. Thus, before the relational shift occurs, children primarily attend to featural similarities between objects. After the shift, they will primarily succeed in analogical reasoning tasks because they are able to reason on the basis of relational features.

Finally, Richland, Morrison, & Holyoak (2006) stresses the importance of cognitive constraints in analogy-making. The idea is that analogy-making generates cognitive loads because it involves the simultaneous manipulation of several relations. Also analogy-making, in general, requires retrieving relations that are not immediately available in working memory when the base situation is presented. Limitations on cognitive resources involved in processing mean that certain types of analogies – in particular those involving conflicts between different types of matches – in particular, perceptual (i.e., attributional) and relational matches – should be harder to make. Children have more limited cognitive resources than adults and, therefore, should find these analogies more difficult to do. In their studies, Richland et al. used scene analogy problems consisting of pairs of scenes illustrating relations among objects. The authors manipulated featural distraction by varying the identity of an object in the second scene. So, for example, if the base scene included a running cat, they added to the target scene an object that was either perceptually similar (e.g., a sitting cat) or dissimilar (a sandbox). Results revealed that stimuli with the similar distractors elicited more errors than the stimuli with the dissimilar ones.

## Goals of the present paper

In the following paper we present results that emphasize the underlying ideas of Richland et al., focusing on the key notion of the competition (or interaction) between the perceptual attributes of the stimuli being processed and the relations between them. The issue of competition between perceptual and relational similarity has been addressed extensively in previous works (e.g., Gentner & Toupin, 1986; Rattermann & Gentner, 1998).In this paper, however, we wish to stress the importance of cognitive factors in the building and manipulation of short-term representations that allow analogy-making to proceed. We suggest that mapping should be seen as a process in which the structures and attributes in the base and target domain gradually become available to processing and, in particular, do not have a constant salience throughout processing (Mitchell & Hofstadter, 1990; Mitchell, 1993; French, 1995).

Our experiments attempt to show the deep context-dependent nature of analogy-making in children. In other words, the solution to a given analogy problem is highly dependent on the degree to which the child focuses on particular dimensions of the stimuli. The relational shift hypothesis suggests that young children do not perceive the related structures in the base and the target, focusing instead on common attributes in the base and target, whereas older children focus on the common structure (Gentner, 1988).

We hypothesize that in many cases younger children are able to perceive the structure but do not use it to make an analogy. What prevents them from making the expected analogy is the nature and salience of the distractors that are proposed together with the expected (i.e., "relational") solution. So, analogies that are formally identical but based on different mapping dimensions -- in this case, shape or color -- do not necessarily lead to the same performance. We also claim that within the same type of analogy, different types of perceptual conflicts, including the absence of such a perceptual conflict, have significantly different effects on performance. We also posit that in the context of forced-choice paradigms, when children chose the non-analogical possibility (i.e., the perceptual match), this does not necessarily mean that they have not seen, or were unable to see, the relational match. It might be that they saw it but did not prefer to choose it, or that they could have seen it, had it not been for the competing presence of more salient perceptual choices.

Unlike Richland et al. (2006) who used semantic relations that require an independent assessment of children's understanding, we used colored geometric shapes that were completely familiar to children. We manipulated the shapes, colors and number of the base and target items, as well as the number of distractors whereas Richland et al. compared a no-distractor condition with a 1-distractor condition.

The remainder of this paper is organized around two experiments. Experiment 1 was a forced choice task in which the relational match was always in competition with another potential target. We manipulated the type and number of perceptual dimensions this potential target shared with the standard. In experiment 2, we used perceptual analogies of the A:B::C:? format. We manipulated the number of distractors, their nature and the mapping dimension (color vs. shape).

# Experiment 1

This experiment is based on a forced-choice task similar to the one used by Christie and Gentner (2007). Children see an initial pair of colored geometric shapes, called the "standard." They must then select among a number of "target" pairs of new colored geometric shapes, the one that is more like the standard pair. Christie and Gentner showed that a majority of children aged 4 chose the perceptual match rather than the analogical match whereas children aged 8 were at chance. Here, we manipulate the colors and shapes of the distractors in the target domain. The desired response is always based on the identity relation "same shape" between the two elements of the standard. For example, the standard might consist of two squares, one blue, one green. There are three conditions for the target pairs (Figure 1):

a. <u>Competition</u>: The two target pairs consist of a pair of different shapes (e.g., circle/triangle) in which one of the objects has the same color as one of the squares in the standard and a pair of identical shapes (e.g., 2 stars). The former is the "perceptual match" – because it shares a color with the standard pair – and the latter constitutes the "relational match" – because it shares the identity relation with the standard pair. Here, there is a competition between the perceptual and the relational matches.
b. <u>Same color</u>: Identical to (a), except that in the "relational" target pair, one of the two shapes shares a color with one of the shapes of the standard.
c. <u>No competition</u>: As above, the two target pairs consist of a pair of different shapes (e.g., circle/triangle) in which neither of the objects has the same color as either of the squares in the standard and a pair of identical shapes. In this case, there is no competition because there is no perceptual match; the only intended solution is the relational match.

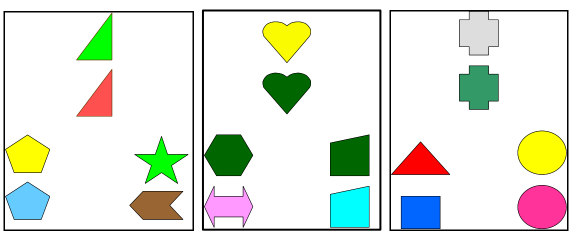
The key comparison will be between the first condition (a) in which there is a competition between the analogical solution and a perceptual solution and the last condition (c) in which the *only* solution is the analogical one. The Same Color condition is interesting because, if children were relying only on perceptual cues, they should answer randomly, whereas in the Competition condition they would be biased towards the perceptual match.

We used a 3 x 3 mixed design with Age (6 years-old, 8 years-old, adult) as a between factor and Match Condition (Competition, Same Color, No competition) as a within factor. The dependent variable was the number of analogical matches.

## Methods

**Participants**. A total of 23 6-year-olds (M = 78 months, range: 72-83 months), 23 8-year-olds (M = 100 months, range: 96-104 months), and 26 adults (university students) participated in the experiment.

**Materials.** Stimuli were made of geometric shapes similar to those used by Christie and Gentner (2007). There were 12 trials each consisting of the standard pair and two target pairs, as described above. The positions of the target pairs were left-right counterbalanced. There were three conditions: Competition, Same Color, and No Competition. There were four trials per condition. Additionally, any given shape could be part of either the standard or the target pairs, in order to avoid choices based on a systematic preference for a given shape. The colors of the shapes were also systematically varied (Figure 1).



*a. Competition* *b. Same color* *c. No competition*

Figure 1. Examples of the 3 conditions: Competition, Same Color, and No Competition.

**Procedure.** The first trial was used to explain the task. Each child then saw 4 trials in each of the 3 conditions. For each trial, the experimenter showed the child the standard and the two target pairs on a computer screen and said, pointing to the standard, “Look at these two items.” And then, pointing at the two target pairs, the experimenter said, “Which one of these two pictures is more like this one [pointing at the standard]?” No feedback was given, except general encouragement.

## Results and discussion

A two-way mixed ANOVA revealed main effects of the between factor Age, F(2, 69) = 4.496, $p$ = .015, $\eta^2$ = 0.12; and the within factor Match Condition, F(2, 138) = 5.02, $p$ < .01, $\eta^2$=0.07; and no significant interaction. A posteriori comparisons (Tukey HSD) revealed that adults (M = 3) gave significantly more analogical choices than children aged 6 (Mean = 2.2) ($p$ < .05). The other comparisons were not significant. They also revealed that the number of relational responses in the Competition condition (M= 2.4) was significantly lower than in two other conditions (M = 2.8, in both cases, $p$ < .05).

In addition, we compared the results from each group to chance using a $t$-test. The value of chance was 2.0 relational responses. At six years of age, none of the conditions differed significantly from chance ($\alpha = 0.05$) even though a trend was observed in the No Competition condition: $t$(22) = 1.78, $p$ = 0.088, $\eta^2 = 0.13$. At eight years old, however, the results for the Same Color and No Competition conditions were significantly above from chance, whereas the Competition condition did not differ significantly from chance. Specifically, for the Same Color condition $t$(22) = 2.45, $p$ = 0.023, $\eta^2 = 0.21$. For the No Competition condition: $t$(22) = 6.01, $p$ < 0.001, $\eta^2 = 0.62$. For the adults, all results were significantly above chance. For the Same Color condition: $t$(25) = 6.46, $p$ < 0.001, $\eta^2 = 0.65$. Finally, for the No Competition condition: $t$(25) = 3.84, $p$ < 0.001, $\eta^2 = 0.40$. Finally, for the Competition condition: $t$(25) = 3.95, $p$ < 0.001, $\eta^2 = 0.41$ (see Figure 2).

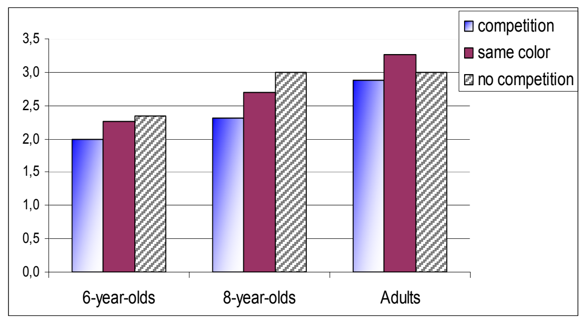



Figure 2. Children’s and adults’ results as a function of condition (chance level: 2)

This experiment was designed to distinguish the situation in which a child sees the analogical match but does not chose it from the situation where the child does not see the analogical match. At eight-years of age it is clear that the children do, indeed, see the analogical match, as shown by the highly significant result ($p$ < 0.001, $\eta^2 = 0.62$) in the No Competition condition. However, in the Competition condition (perceptual match competing with the relational match), their performance does not differ significantly from chance. This indicates that, while they see the analogical match – as demonstrated by their performance in the No Competition or the Same Color conditions – they are equally drawn to the perceptual match.

The Same Color condition was a condition with conflicting perceptual cues. We hypothesized that if children had a strong bias towards perceptual dimensions, they would answer randomly, since both target pairs share a color with the standard. In fact, their performance did not differ significantly from the No competition condition, suggesting that, once the shared perceptual feature was detected, they were able ignore it and chose a relational solution. In other words, this condition suggests that they can inhibit perceptual matches. However this was true for 8-

year-old children only. At six, their answers did not differ significantly from chance. The comparison between the three groups reveals an interesting pattern. The younger children had a non significant tendency to choose the relational solution in the No Competition condition. Eight-year-olds also selected the relational solution in the Same Color conditions, whereas adults selected it in all three conditions. Thus, our results show a hierarchy of performance that is consistent with a hierarchy of increasing cognitive demands.

## Experiment 2

One problem with the Competition condition in Experiment 1 is that both the perceptual and the relational choices are valid solutions to the task of choosing a single Target pair that is "most like" the Standard. There is no pressure to choose one solution over the other in the task. Gentner and colleagues have shown that there is a developmental trend from perceptually-based choices to relationally-based choices, despite the lack of pressure towards any of the two solutions (e.g., Christie & Gentner, 2007). However, it remains possible that in Experiment 1, especially in the Competition condition, children's choices were based on what they preferred (i.e., the perceptual match), rather than on their ability to detect the relational target. For this reason, we adapted the first experiment to one that more closely fits a traditional A:B::C:? analogy-making paradigm, i.e., one in which the "relational" choice is the more valid one. In the four conditions of this experiment, we attempt to progressively increase the "perceptual noise" in the distractors, in order to increase the processing load associated with making the analogy.

In this experiment, we again used colored geometric shapes. We called the first pair (A:B) the Base Pair and the (C:?) pair the Target Pair. The two stimuli in the Base Pair are related by either having the "same shape" or the "same color". The third stimulus (C) had to be matched with a fourth stimulus (D), such that the relation between C and D was the same as the relation between A and B. (See Figure 2). We created four conditions in which we manipulated the type of conflict and the number and type of distractors.

This experiment was a 2 x 2 x 4 mixed design with Age (6-year-olds and 8-year-olds) as a between factor, Match-Dimension (Color, Shape) as a within condition and Match Condition (Two-Choice-Competition, Four-Choice-No-Competition, Four-Choice-Single-Competition, and Four-Choice-Three-Competitions) as a within factor. The dependent variable was the number of correct relational matches (see below for more details).

### Methods

**Participants**. A total of 19 six-year-old children (M: 77 months; range: 73-84 months) and 20 eight-year-old children (M: 102 months; range: 97-108 months) participated in the experiment. A control group of 10 adults from the University of Poitiers, unaware of the purposes of the experiment, also participated.

**Materials.** There were four conditions. The experiment was composed of 20 trials, 4 training trials, and 16 experimental trials. Each condition was composed of 4 trials. In the first condition, the Two-Choice Competition condition, there were only 2 target choices, a relational item (the correct solution) and a perceptual distractor. In the other conditions, we progressively increased the "perceptual noise" from the distractor items. The second condition was a Four-Choice No Competition, in which there was only one relational item and three distractors that shared no obvious perceptual feature with the C term. The third condition was a Four-Choice Single-Competition condition in which there was one relational choice and where one of the distractors was a perceptual match and the remaining two distractors shared no obvious perceptual feature with the C term. In the final condition, the Four-Choice Three-Competition, there was one relational match and three distractors, each of which was a perceptual match, one with the A term, one with the B term, and one with the C term.

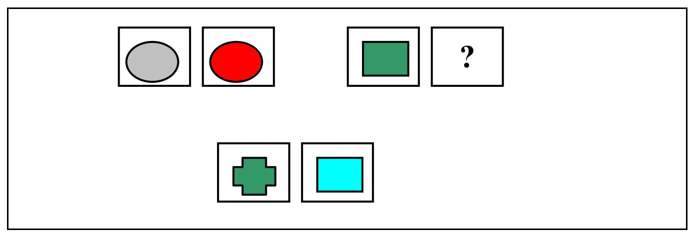



Figure 2: the analogy display used in Experiment 3; the two stimuli in the bottom raw illustrate the Two-Choice competition condition (see text)

**Procedure.** The children saw the stimuli on a computer screen. They saw the A:B pair and the C term shown in an array with the first two items grouped together to the left of the screen. The C item was alone on the right of the screen and next to the C item there was an empty square with a question mark. Each of the items was drawn in a box (Figure 3). They studied these items and, without seeing the Target items, were asked to predict what image they would put in the box with the question mark in order to complete the pattern. They were then shown the Target items and were asked to point to the one that best completed the series of items. (This procedure was patterned after Goswami & Brown, 1990). The first four trials were training trials.

### Results and discussion

We ran a three-way mixed ANOVA on the data with Age as a between factor and Match-Dimension and Match-Condition as within factors. We did not include the adults in the analysis because they made no mistakes during the experiment. The ANOVA revealed a significant main effect for each of the factors and no interaction. Children aged eight performed significantly better than 6 year-olds, $F(1, 37) = 7.87$, $p < .05$; $\eta^2=0.18$; shape analogies were better understood than color analogies, $F(1, 37) = 21.08$, $p < .001$;

$\eta^2$=0.36. The effect of match condition was also significant, F (3, 111) = 7.58, $p$ < .01; $\eta^2$=0.17. A posteriori analyses (Tukey HSD), showed that the Two-Choice-Competition condition differed significantly from the Four-Choice-Three-Competition (M = 1.44 vs. 1.19, out of 2) and the Four-Choice-No-Competition differed significantly from the Four-Choice-Single-Competition and the Four-Choice Three-Competition conditions (M= 1.53 vs. 1.25 vs 1.19, respectively).

The experiment shows a general increase in performance with age. Interestingly, the Four-Choice Single-Competition and the Four-Choice-No-Competition conditions did not differ significantly, whereas the latter differed significantly from the Four-Choice-Three-Competition condition, which suggests that adding common perceptual features increased the overall difficulty of the task.

Of considerable interest was the general difference between Shape and Color analogies. Shape was significantly favored over color. This would presumably indicate that shape is more salient than color for children. Since the shape and color analogies have exactly the same formal structure, this difference cannot be attributed to a relational shift or a difference in terms of knowledge. In fact, children can sort stimuli on color as efficiently as on shape.

In the Four-Choice Single-Competition, another difference between the Color and Shape conditions is the number of choices among distractors that share no feature or relation with the C term. There were four such errors in the Shape condition against eight in the color condition. Essentially, an equivalent difference was obtained in the Four-Choice-Three Competition condition in which children selected more stimuli that had a perceptual match in common with one of the stimuli of the base pair in the color condition than in the shape condition. These two results, though only suggestive, are compatible with the idea that the color condition generated more "cognitive noise" than the shape condition.

Finally, the result obtained for the Four-Choice No Competition condition is of interest. Even though the relational solution was also a perceptual match, children of both age groups were far from perfect, especially for the color analogies. One explanation is that young children also tried to find solutions for the other stimuli. As mentioned above, this search might have contributed to the increased processing load of the task, which in turn gave rise to errors.

## General Discussion

The results of our two experiments fit well with the hypothesis that limitations in children's processing load capacity affect their performance in analogy-making tasks. The results for the eight-year-olds in our study suggest that these limitations continue at least through mid-childhood (see Richland et al., 2006). In contrast to Richland et al. (2006) or Mix (2007), we attempted to limit the necessity for semantic knowledge by constructing analogy problems based on geometric shapes and perceptual dimensions with which even the youngest children in our study were well familiar. Consequently, differences between the conditions could not be accounted for in terms of differences in knowledge required to solve the problem.

The age hierarchy obtained in Experiment 1 (i.e., the tendency to choose the relational match in the No Competition condition at age 6, in the Same Color condition at age 8, and in all three conditions for adults) is compatible with the hypothesis of increasing development of executive function with age. The difference between the Two-Choice Competition and the Four-Choice Three-Competition conditions can also be explained by the increased cognitive cost of inhibiting a larger number of potential perceptual choices in the latter condition.

The performance in the No Competition conditions in both experiments is also revealing. Given that there was no other consistent solution in the analogy, the errors likely reflect children's search for a solution across the target stimuli. Their errors arguably reflect their inability, because of excessive cognitive load, to consider all the possibilities at the same time, keeping only the best of the lot. This does not reflect an intrinsic ambiguity in the task itself, since in Experiment 2, the adults made no mistakes in any of the conditions.

Since children are able to sort and categorize stimuli according to color before the age of six, we do not interpret the color-shape differences above in terms either of acquired knowledge or of the relational shift hypothesis. This difference is compatible with the general notion of a shape bias. Although this bias has received various interpretations, it has been repeatedly shown that children are relying on shape more than on other dimensions, such as color to generalize concepts (Landau, Smith & Jones, 1998; Diesendruck & Bloom, 2003). In many situations shape is more "important" or relevant than color cues. This would explain why children spontaneously focus on shape and why they succeed more often in the shape condition than in the color condition. Interestingly, this bias disappeared in the adult group where performance was perfect in both dimensions.

More generally, as mentioned above, our results are similar to results obtained by other authors (e.g., Richland et al., 2006, on semantic analogies; Mix, 2007, on number equivalence). They all refer to the idea that salient irrelevant properties interfere with the construction of the analogical solution. Our experiments attempted to explicitly and systematically manipulate the nature and the number of these perceptual properties.

In general, these results are compatible with the idea of the involvement of processing constraints: when confronted with an analogy, we look for potential solutions or construct these solutions by testing various hypotheses (i.e., features and relations between features). When there is no obvious solution, we construct and compare different possible solutions. These comparisons between the base stimuli and various stimuli in the solution space generate cognitive loads associated with executive functioning. To find a good solution, one has to inhibit other salient, but poorer solutions. One must remain flexible enough to replace a solution that appears to be poorer compared to a newer one, but still be prepared to return to one's first choice later on. During the analogy-making process, it is also necessary to maintain in working memory previous solutions and/or the relations. This also has a cognitive cost that is crucially involved in the final choice of a solution. To the best of our knowledge, current models of analogy-making in children do not make these processing constraints explicit. Our views regarding the role of working memory are similar to Halford's views (e.g., Halford, 1993). He has defined relational complexity in terms of the number of sources of variation that are related and must be processed in parallel. However, we also want to stress the role of inhibition and flexibility.

In conclusion, we have argued for the notion of a competition between perceptual features and relational structure in understanding analogy-making. We attribute children's performance on the tasks presented in this paper to the degree of cognitive load engendered by the perceptual features in competition with the relational information.

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