Semantic Analogies by Young Children: Testing the Role of Inhibition

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Abstract

The present study directly tests the relationship between children's performance in an analogy-making task involving semantic analogies and their inhibitory-control capacities tested with the Day-Night test (Gerstadt, Hong, & Diamond, 1994). Our claim is that the development of analogy making can be best studied in terms of developmental changes in executive functioning, specifically, inhibitory control (Richland et al., 2006; Thibaut et al., 2010a,b). The selection of common relational structure requires the inhibition of other salient, semantically related matches. Our results show that children with lower inhibition scores had lower scores in an analogy task of the A:B::C:D type, especially for analogies constructed with pairs of weakly semantically associated items (e.g., *man-bed*). The results agree with our analogy-making account. We also show that analogies with perceptual distractors were easier to solve than those with semantic distractors.

Keywords: Analogy-making, development, executive functions, inhibition.

Introduction

Analogy-making is a fundamental cognitive tool with which children gradually make sense of their world. Extensive work suggests 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, Goswami, 1992). Further, it is well established that, while attribute-matching, in general, 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).

There are two main explanations of the development of analogy-making in children. First, children's development in analogy-making tasks can be explained in terms of the gradual increase over time of their structured knowledge of the world (Goswami & Brown, 1990; Vosniadou, 1995). According to Goswami (1992, 2001), analogical reasoning is already present in infancy and it is only the lack of conceptual knowledge in one of the domains involved in the analogy that prevents children from deriving the correct analogies. This view separates the knowledge required to do the analogy from the structure mapping process itself. A second, more recent, line of research emphasizes the role and development of children's executive functions. In this view inhibition plays a central role, especially when salient associations come immediately to mind, but are not relevant to the current analogy problem (Richland, Morrison, and Holyoak, 2006; Thibaut, French, & Vezneva, 2010a and b; see also Davidson, Amso, Anderson, Diamond for a discussion of the development of executive functions). Analogy making also requires cognitive flexibility when the solution does not come immediately to mind or when new relations must be generated and tested.

Richland, Morrison, & Holyoak (2006) and Thibaut, French, Vezneva (2008; 2010a, 2010b) have recently stressed the importance of cognitive constraints in analogy-making (see also Halford, Wilson, & Phillips, 1998, for a related view). We view analogy-making as a search in a space of relations. The number of relations holding between any A-B pair is potentially intractably large because, depending on the context, any number of different relations might be relevant (see Murphy and Medin, 1985; Chalmers, French & Hofstadter, 1992; Hofstadter et al., 1995; French, 1995; Mitchell, 1993; Thibaut & Schyns, 1995; Thibaut, 1991; Thibaut, 1997).

In order to test the role of executive functions in analogy-making in children, Richland, Morrison, & Holyoak (2006) used scene analogy problems consisting of pairs of scenes illustrating relations between objects and manipulated featural distractors by varying the identity of one of the objects in the second scene. Their results showed that when the distractors were perceptually similar to the focal item in the base scene, more errors were made than when the distractors in the target scene differed from the focal item.

Thibaut, French, Vezneva (2010a) used geometrical shapes. In an A:B::C:D paradigm, children were influenced by the type and number of perceptual distractors. They were also influenced by unstructured random textures (i.e, perceptual noise). Reaction times, together with patterns of errors, also revealed different patterns for the three age groups under scrutiny.

Thibaut, French, and Vezneva (2010b) used semantic analogies and explored the role of the association strength between items making up the A-B and C-D pairs with 4- and 5-year-old children. They argued that strongly associated items (e.g., *bird* and *nest*) generate different processing constraints compared to weakly associated items (e.g., *goat* and *grass*). In the case of weaker associations, participants have to search the "relation space" more extensively and to inhibit any strongly associated items that are irrelevant to the analogy at hand.

In this context, Thibaut et al. (2010b) hypothesized that a difference in association strength would mean that children, having more limited cognitive resources than adults, would find these analogies more difficult to do. They 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) and manipulated the number of semantic distractors (1 or 3). Their results revealed a difference between weak and strong analogies especially when the number of distractor items was high, in this case, three. This is compatible with the idea that a greater number of related distractors would be harder to inhibit (and thus, ignore) than a single semantic distractor. Interestingly, strong analogies were largely unaffected by the number of distractors most likely because the relations between A-B and C-D item pairs were sufficiently strong that they were not interfered with by the semantic distractors. In contrast, when the problem involves weakly associated items, mapping the A-B pair on to the C-D pair requires more than simply accessing obvious semantic dimensions of the items and the problem is, therefore, more difficult to solve.

Goals of the present paper

In what follows, we use the A:B::C:D forced-choice paradigm developed by Goswami and Brown (1990) and make use of the weak-strong distinction made by Thibaut et al. (2010b). Thibaut et al. (2010a, b) and Richland et al. (2006) manipulated factors that gave differences in performance that were interpreted in terms of cognitive control (e.g., the more related the distracters, the greater the amount of inhibitory control required). However, the authors had no independent measure of their participants' executive functions. In particular, they had no measure of children's inhibitory control.

To overcome this difficulty, we will adopt an individual-differences approach in which we will assess participants' inhibition capacities independently with the Day-Night test (Gerstadt, Hong, & Diamond, 1994). We will relate this independent measure of cognitive inhibition with their performance on the analogy task. *Our central hypothesis is that children with higher inhibition scores should perform better than children with lower scores.* Specifically, in light of the results obtained in Thibaut et al. (2010b) on strong versus weak analogies, we would predict a larger difference in performance between good and poor inhibitors in solving weak analogies, i.e., analogies in which the items in the A-B and C-D pairs are weakly associated. Solving weak analogies should require more inhibition because each item activates associated items that are not relevant to the solution of the analogy (since as mentioned above the analogy is built around weak associations). By contrast, strong analogies involved highly associated items and, as a result, the relation between the items in the A-B and C-D pairs is easier to attend to.

To the best of our knowledge, there are no studies in which the status of the semantic knowledge involved in an analogy and executive control performance are independently controlled.

We also manipulated the status of the distractor. We contrasted semantic with perceptual distractors. Half of the trials had one semantic distractor (e.g. *bone* in the case of a pair *dog-doghouse*). In many studies of analogy-making in children, both perceptual and semantic distractors are included among the possible solutions (Goswami & Brown, 1990; Rattermann & Gentner, 1998). The evidence regarding the influence of each type of distractor is mixed. For example, in Goswami and Brown (1990), it seems that participants chose thematically (i.e., semantically) related distractors over perceptual distracters, whereas the Rattermann and Gentner (1998) found the opposite. Moreover, if both types of distractors are present in the same problem, even if children preferentially select one over the other, this says nothing about the influence of a single distractor of either type. For this reason, in the analogy problems in the work that follows, only a single type of distractor was used.

Perceptual versus semantic distractors

The relative influence of perceptual versus semantic distractors is an important issue for several reasons. First, in the context of the role of inhibition on analogy making, it is important to disentangle the respective influence of the two types of distractors across ages because each type could influence performance in very different ways.

Perceptual distractors raise the general issue of the role of perception in early conceptual development (Thibaut, 1999). There is a view of conceptual development that posits that categorization in young children is strongly influenced by perceptual similarities. Later, as they gain semantic knowledge about the world, this knowledge trumps perceptual information (see e.g., Imai, Gentner, & Uchida, 1994; Jones 2005). This view is the basis of the so-called "relational shift hypothesis" (Gentner & Ratterman, 1991; Ratterman & Gentner, 1998). This hypothesis holds that when children solve analogies, the younger they are, the more they are attracted by perceptual-match solutions, the older they are the more they rely on relational aspects between items in the problem. One prediction based on this hypothesis would be that perceptual distractors would influence younger children more than semantic distractors, with the reverse being true for older children because, for older children, it is easier to recognize that a perceptually similar distractor has nothing in common with the task at hand.

The influence of semantic distractors might be of a different type. Semantic distractors are in the same – conceptual – space as the analogical solution (the D item). Both activate conceptual representations that must be compared in terms of the relation to be found. In the case of *bird:nest:: dog: ?*, solutions such as *doghouse* and *bone*, are both semantically related, but ultimately, participants who solve the problem correctly must understand that the semantic relation *dog-bone* does not fit in the context of the *bird:nest* relation. In other words, the issue is whether children will be more influenced by distractors in the same semantic space as C (sharing conceptual features with C) or by distractors belonging to the same perceptual space as C (i.e., sharing perceptual features with C).

The experiment we report has a 3x2x2 design with Age (4 and 5 years old) x Association strength (strong or weak) x Distractor-type (perceptual or semantic).

Experiment

Participants

58 children took part in this experiment: thirty 4-year-old children (M = 55 months) and twenty-eight 5-year-old children (M = 66 months). Informed consent was obtained from their parents.

Materials

The experiment was composed of 14 trials, divided into 2 practice trials and 12 experimental trials. Each of the four conditions (Association strength x Type of distractor) consisted of 3 trials. Each trial consisted of 7 drawings: A, B and C and the 4 drawings that composed the solution set that included the analogical match and either one semantically related distractor (in the semantic-distractor condition) or one perceptual-distractor (in the perceptual distractor condition) and two items that were semantically and perceptually unrelated to C (Figure 1).

The strength of the semantic association between pairs of words and their corresponding picture was determined by university students. They were asked to rate to what extent each item of a pair made them think of the other. This was done for the A-B and for the C-D pairs separately. 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. On the basis of these results, we were able to rate pairs for the experiment as either strongly related (i.e., both the AB and the CD pairs were strongly related) or weakly related. Other participants rated the perceptual similarity between C and D on a 1-7 scale. The perceptual similarity between C and D was low (below 3). The perceptual distractors were based on how perceptually similar they were to C (5 or more on 1-7 scale) and how semantically dissimilar they were to C (3 or less on the 1-7 scale). The semantically-related distractors had to be rated as strongly semantically similar to C (5 or more) and perceptually dissimilar to C (3 or less).

The experiment was run with E-prime® software. We used a 19 inch touch screen to record children's answers and their reaction times.

Inhibition test (Day-Night task)

We used the Day-Night test (Gerstadt, Hong, & Diamond, 1994) to assess children's inhibition capacities. The test was composed of two sets of 32 items, each set consisting of 16 pictures of the sun and 16 pictures of the moon and stars. One set is used for naming (control condition) and the other is used to assess inhibition capacities (experimental condition). In the interference-inhibition condition, participants have to inhibit the dominant answer. In other words, the child must say "day" when he/she sees a picture of the moon and stars, and he/she must say "night" for the picture of the sun (see Figure 2).

Procedure

Two experimenters saw the children individually at their school in a quiet room. Each child was seen twice, once for the analogy task, once for the inhibition task. The order of the tasks was counterbalanced across participants.

Analogy task.

Children were seated in front of the touch screen and were asked to keep their dominant hand, always at the same place, in front of the screen on the desk. This was done in order to keep the hand-screen distance constant across trials and participants, more or less 30 centimeters. Children were instructed that they would have to touch the stimulus on the screen corresponding to their choice "as soon as they had found the solution". They were told that they could touch the screen only once per trial.

Each trial began when the experimenter pressed the space-bar. The 7 stimuli for each trial were displayed simultaneously. The A:B pair and the C item were 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 C there was a box with a question mark. The four solution items were displayed on a separate row, beneath the A B C [?] row (see Figure 1). Children were asked to point to the item in the lower row that best completed the series of items in the upper row (cf. Goswami & Brown, 1990). The first two trials were training trials and children received feedback for them. The reaction time was defined as the interval of time between the onset of stimulus presentation and the participant's response.

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.

Inhibition task

Children saw the control set first and had to give the name of the stimulus displayed on the picture as fast as possible, i.e., « night » for the moon-and-stars picture and « day » for the sun picture (Gerstadt & al, 1994). For the experimental (inhibition) set, children were requested to say « day » as fast as they could for the moon-and-stars stimulus and « night » for the sun stimulus. The experimenter counted the number of errors and computed children's reaction times.

Results

Performance was measured as the percentage of valid relational (i.e., most obvious relational) matches. We eliminated all trials in which either the children did not understand the semantic relation between the A and B items or between the C and D items to be sure that they had not failed simply because they did not have the relevant knowledge for these pairs.

We ran a 3-way mixed ANOVA on the data with Age (4 vs. 5) as a between factor and Association strength (strong vs. weak) and Distractor-type (perceptual and semantic) as within factors.

As expected, children aged 5 performed better than 4 year-olds, $F(1, 56) = 9.70$, $p < .01$, $\eta^2 = .15$. Second,

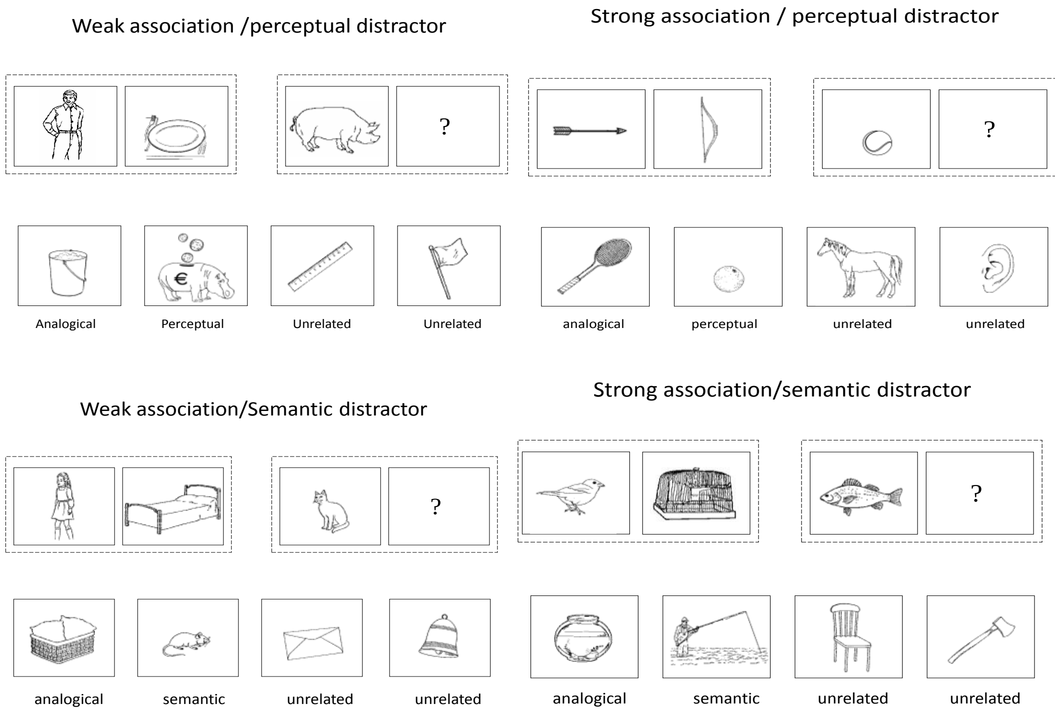

Figure 1: the four types of trials used in the experiment.

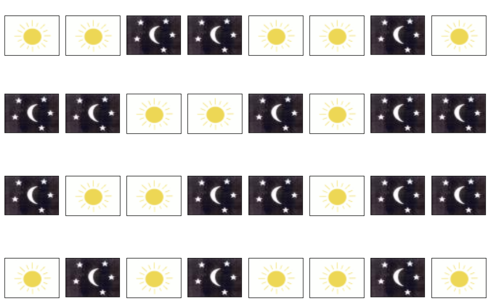

Figure 2: example of the set of stimuli used in the Day-Night task.

performance was significantly better on analogies with strong AB and CD relations than on those with weak AB and CD relations, $F(1, 56) = 18.76$, $p < .001$, $\eta^2 = .25$ (proportion correct in weak condition: M = 0.44, in strong condition: M = 0.58). Finally, performance was better on analogies with a perceptual distractor than for those with a semantic distractor, $F(1,56) = 8.44$, $p < .01$, $\eta^2 = .13$ (perceptual distractor, M = 0.57; semantic distractor, M = 0.46).

Since we were primarily interested in the relationship between inhibition performance and analogy-making performance, we defined a second variable, Inhibition status. This variable was a measure of the number of errors produced on the day-night task. Participants with 3 errors or less were defined as good inhibitors and participants with 5 or more errors were defined as "poor" inhibitors. This left 7 participants out of the analyses (i.e., the "average" inhibitors). With this new factor, we ran a three-way mixed ANOVA on the same data with Inhibition status (poor vs. good inhibitor) as a between factor, Age as a covariate, Association strength (strong vs. weak) and type of distractor (perceptual vs. semantic) as within factors. Results revealed a significant interaction between Association strength and Inhibition status, F(1, 47) = 4.14, $p<.05$, $\eta^2 = .08$. A Tukey HSD post-hoc test revealed (Figure 3) a significant difference between strong and weak associations (M = 0.58 and M = 0.34 respectively; p<.01).

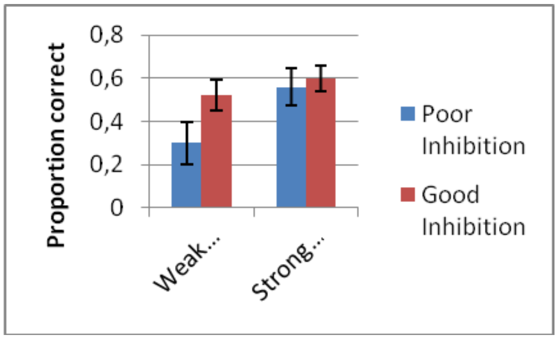

Figure 3. Interaction between Association strength and number of errors on the Day-Night task.

General discussion

The present experiment produced two important new results, namely – first, a significant interaction between children's inhibition capacity and the association strength of the item pairs; second, a significantly better performance for analogies with perceptual distractors compared to those with semantic distractors.

The result in Figure 3 is a replication of the association-strength effect obtained by Thibaut et al. (2010b) in a different experimental context. It was obtained with a single distractor, which was either semantic or perceptual. One important purpose of the present study was to explore the connection between analogy-making performance and inhibition capacities. Our results revealed a significant interaction between association strength and inhibition capacity. In other words, children with poorer inhibition capacities performed more poorly than children with better inhibition capacities on analogies involving weakly associated items. This result makes perfect sense in light of our executive function and search space hypotheses. When associations between items are weak, the search for an appropriate solution becomes more difficult for at least two reasons: 1) the search space is broader because the analogical solution does not come immediately to mind 2) when strong competitors, either perceptual or conceptual, are present during the search, they must be inhibited in order to find the analogical solution.

This result stands in stark contrast to Goswami and Brown's (1990) claim that children find the analogy as soon as they understand the relationships between the components that are involved in it. According to Goswami and Brown's theory of necessary knowledge, manipulating the association strength between the analogy components should not have influenced children's performance. We tested children's knowledge of the relations after the analogy-making task. As mentioned in Thibaut et al. (2010b), the majority of the analogies used in Goswami and Brown's (1990) experiment were of the strong-association type. The present interaction shows that weakly associated items puts additional cognitive constraints on the task – namely, analogies involving weak associations require the search space to be explored more extensively and, if distractors that are semantically or perceptually related to C are present, more inhibitory control is required.

The second purpose of the present research was to examine the role of perceptual and semantic distractors. Our results showed that analogy problems with semantic distractors were more difficult to solve than those with perceptual distractors. There was no interaction with Age or Distractor-type. One could argue that results can be explained by differences in level of intelligence. If this interpretation was correct, no interaction should have been obtained and the better inhibitors should also be better in the strong case: indeed results are from perfect even in the strong condition. We also assessed children's cognitive capacities with a vocabulary test, the PPVT. In the developmental literature, general intelligence is often assessed with this type of test (see, e.g., the mental retardation or aging literature). In our case there was no significant correlation between vocabulary and the Day-night test, suggesting that both tests tapped into different cognitive capacities. Thus, one cannot argue the day-night test merely reflected general intelligence.

As mentioned in the introduction, the difference between semantic and perceptual distractors has not been systematically explored in the literature. When they were introduced in previous experiments (Thibaut et al., 2010b), both types were present in each trial. Thus it was difficult to determine their respective importance.

One central question in the present paper was, therefore, whether children's performance would be more affected by competing semantic knowledge (the semantic distractors) or by the presence of perceptual similarities with C. In other words, would it be easier to inhibit distractors that were perceptually similar or semantically similar to C? Our results showed that children did better for trials with perceptual distractors compared to trials with semantic distractors. In the conceptual development literature, it is often argued that younger children are more influenced by perceptual similarities (e.g., Imai, Gentner, & Uchida, 1994; Smith, 2005) in a wide range of cognitive tasks (e.g., reasoning, categorization, analogies). We agree with the idea of a strong influence of perceptual similarities, but our results also show that semantic similarities can have a greater influence.

In conclusion, we have presented work that demonstrates an association between children's inhibition capacities and their analogy-making performance. A theory of analogy-making based on mechanisms of cognitive load appears to provide a relatively straightforward explanation of these data, whereas it is hard to see how other theories that are not based on cognitive load could explain these results.

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