Does Analogy Facilitate Transitive Inference in Young Children?

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Abstract

Both transitive reasoning and analogy-making are present at very early stage of human development and the question arises whether the two developmental trajectories interact with each other. We are presenting an experiment with 4 years old children to test the hypothesis that the analogy-making capabilities can scaffold and facilitate the development of transitive inference and the empirical data support this hypothesis.

Introduction

Transitive inference is the simplest form of deductive reasoning that combines two premises R(a,b) and R(b,c) and makes the conclusion that R(a,c). For example, if John is stronger than Peter, and Peter is stronger than Bill, then necessarily, John is stronger than Bill. Piaget (1921) was the first psychologist who introduced the topic of transitive inference in the developmental framework. He and his collaborators claimed that the ability of transitive reasoning is developed relatively late during the stage of concrete operations (Inhelder & Piaget, 1958, 1964): first at the age of 8 about size relations like "bigger than", and even later on about other relations like "heavier than".

The developmental trajectory of transitive reasoning has been extensively studied and disputed in the literature and many psychologists found evidence that this ability is present much earlier in the development than it was assumed by Piaget. Thus since 1970s the research in the area was dominated by the debate about the age at which children can be considered to make transitive inferences. According to Trabasso (1977) and Halford (1993) this age depends on the specific procedure that tests the ability and under certain circumstances even children at the age of 4 can exhibit this capacity. McGonigle and Chalmers (1977) challenged the field by demonstrating that monkeys can also make transitive inferences. More recently it has been demonstrated that rats (Roberts & Phelps, 1994), pigeons (von Fersen et al, 1991, Lasareva & Wasserman, 2006), and even fishes (Grosenick, Clement & Fernald, 2007) do make transitive inferences. It has been argued that transitive inference is important for the survival because it allows the animals to determine social dominance of other animals without getting into mortal fights.

A very similar debate has also dominated the field of analogical reasoning development. Inhelder and Piaget (1958, 1964) claim that analogical reasoning is a type of reasoning which develops during the formal operation stage i.e. after 11 years of age. However, like in the field of transitive inference, modern researchers have demonstrated that analogy is present at very early age if not from birth (Goswami, 1991, 2001, Kotovsky & Gentner, 1996). And again there is now some evidence that Chimpanzees (Gillan, Premack, & Woodruff, 1981; Oden, Thompson & Premack, 2001), Baboons (Fagot & Parron, 2010), Capuchin monkeys (Truppa et al, 2010, 2011), and even New Caledonian Crows (Taylor et al., 2007) can make analogies.

This research suggests that both transitive inference and analogy-making are very old evolutionary and are also present from very early age in human beings and the question arises whether the development of the two capabilities interact with each other.

Kokinov (1990, 1992) suggested that in fact deductive, inductive and analogical reasoning might be produced by the very same mechanisms. His proposal is that the analogical reasoning mechanisms are the basis and they are then used for deduction and induction as well. He obtained some experimental support for this proposal using adults. Halford (1993) suggested that deductive reasoning development is based on the already developed analogical reasoning capacities, but did not present empirical evidence for his claim. Goswami (1995) tried to find support for that idea by providing analogies to children in the class inclusion problem, but could not find an effect of the analogy. Based on the two proposals above Mutafchieva and Kokinov (2008) designed an experiment to test whether analogy can actually help children make better transitive inferences and obtained positive results. However, the doubt remained whether this is really transitive reasoning. The current paper presents an experimental study that replicates and further extends these initial findings making sure that children are making proper transitive inferences.

Another topic of hot debate is the methodology of measuring transitive inference capabilities. Various authors have suggested various procedures and it might be that they measure different aspects of the transitive reasoning abilities. Inhelder and Piaget (1958, 1964) used the original definition of transitive inference with three objects where the premises are presented as two comparisons and the question is about the relation between the two objects unseen together. Later on, however, Bryant and Trabasso (1971) and McGonigle and Chalmers (1977) have used a form of the task with 5 items in a series with extensive training of some pairs and asking about others that are

unseen before. This procedure was meant to eliminate the potential memory problem that children can have remembering the premises. Pears and Bryant (1990) finally eliminated the training phase since there was severe criticism about the role of this training plays.

Sternberg (1980) introduced another version of the three object task, namely if A is shorter than B, and B is shorter than C, which is the shortest? We are using this version in our study. However, there is serious potential problem here. As Piaget emphasised crucial for the transitive inference is the understanding of the relativistic nature of the relations, i.e. that relations, unlike properties which are constant characteristic of an object (e.g. if the object is red it remains red during the whole experiment), are dynamically changing depending on the specific object you are comparing it to. For example, object B may be bigger than object A and at the same time be smaller than C, i.e. being "bigger" is not a property of the object itself. Inhelder and Piaget (1958, 1964) claim that this ability is mastered much later in life – in the stage of concrete operations, while prior to that stage children think that relations are absolute properties of the objects – properties like "larger" and "smaller" are mutually exclusive and it is not possible to attribute them to one and the same object.

In order to test whether children have actually obtained this relativistic understanding of relations and thus exhibit proper transitive inference we have designed a new procedure in which we first show children two separate relations like A is stronger than B, and B is stronger than C, then we ask which is the strongest. Let suppose that the child correctly responds that A is the strongest. Then we add a new object D and say that D is stronger than A and ask children which is the strongest object now. Alternatively in half of the trials we add a new object E and say that C is stronger that E and ask the child which is the strongest now. If children understand correctly the nature of the transitive inferences they have to switch to the new object D in the former case, but keep insisting that A is the strongest in the latter case. We believe this is a stronger and more conservative test of transitive inferences capacity and have introduced it in the current study.

There is another innovation in the test procedure. Since it is natural for children, we speak of how one animal is stronger than another one (e.g. this bear is stronger than this bear). If the animals were visually available than no inferences would be needed and children would visually find the strongest animal, that is why we are presenting the animals hidden in boxes and children have to remember that the bear in this box is stronger than the bear in that box. In addition, to make the task even more complicated we presented the three boxes not in a linear order, but in a triangular configuration. This complicates the task of children according to the "spatial model" (DeSoto, London & Handel, 1965, Huttenlocher, 1968) which assumes that transitive inferences are made based on a linear spatial mental model built in the process of understanding of the premises. As you will see, however, the triangular configuration is important for our manipulation and makes it possible to compare every two objects equally easy.

Finally, the manipulation in the experiment is the introduction of an analogy between the three (or four) boxes in the triangle (rectangular) configuration and a train that is taking turn. In the train the stronger animals are pulling the next ones. In this way we are trying to ground the abstract knowledge of children about "being stronger" with their familiar experience of being able to pull. This is further supported by using physical "draw-bars" between the wagons of the train. In both the experimental and control groups there is a second set of animals on the table which belongs to the experimenter and these animals are not hidden, i.e. the child can visually judge which is stronger than which and which is the strongest. We know from previous studies (Mutafchieva & Kokinov, 2007a, 2007b) that the child can possibly make a mapping between the two sets of animals (the experimenter's and their own) and we assume that this should facilitate the inference process. The difference is that in the experimental group the train analogy is introduced, while in the control group it is not.

Experiment

The goal of the present experiment was to find out whether an analogy with a familiar domain that is grounded in children's physical experience (like the train analogy of pulling) would facilitate the transitive inference while we measure also children's understanding of the relativistic nature of relations.

Hypothesis

Our hypothesis was that when provided with the train analogy children would improve their performance on the transitive inference task and would demonstrate understanding of the relativistic nature of relations.

Design

The experiment had a mixed design.

The *between-subject factor* had two levels:

• *Control condition:* one visible and one hidden set of objects were presented, but no analogy was provided;.

• *Analogy condition:* one visible and one hidden set of objects were presented, and each set was described as a train with wagons that are connected with draw-bars.

The *within-subject factor* was the *number of objects* participating in the object series:

• First measurement – after presenting the two sets of *three objects*.

• Second measurement – after adding a *fourth object* to each set.

Children in both conditions participated in both measurements of the within-subject factor.

The dependent variable was the number of correct responses to the transitive inference tasks and since there were five trials in each session the value could vary from 0 to 5.

Stimuli

Eight animals of the same type were used in each trial: 8 bears, 8 swans, 8 mice etc. In the first measurement 6 animals were presented, divided in two sets of three animals of the same type – one set of 3 animals for the experimenter and one for the child. There was a big, medium and small animal in each set. The corresponding objects from the two sets were of different absolute sizes - for example the biggest mouse from the experimenter's set and the biggest mouse from the child's set had different sizes. In the second measurement a fourth animal of the same type was added to each set. In addition, in the Analogy condition six draw-bars were used to connect the wagons of the train – three for the experimenter's set and three for the child's set (Figure 1a and 1b, correspondingly).
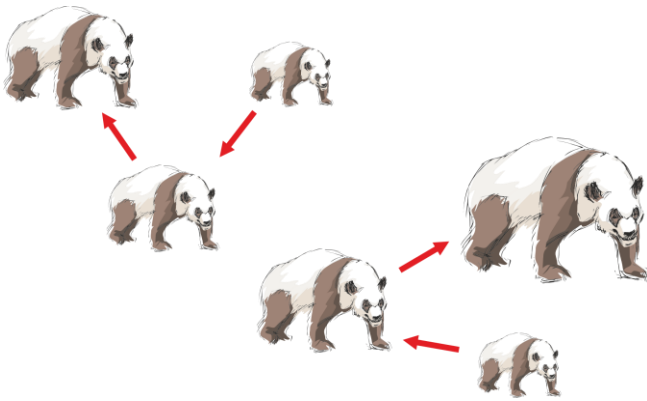

Figure 1a. Example of the stimuli used in the Analogy condition in the first measurement. The biggest object from the upper set was the same absolute size as the medium object from the lower set. The objects from the child's set were hidden under white boxes (Fig. 2)
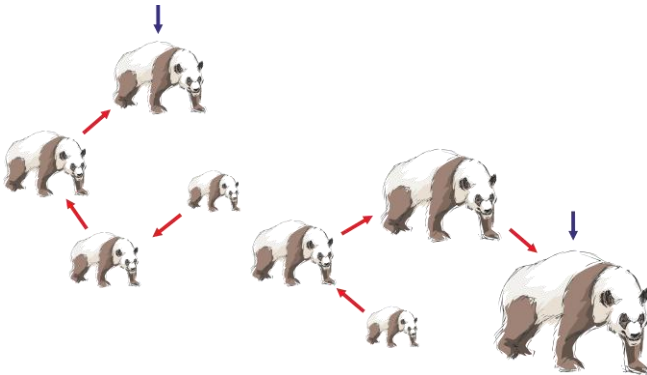

Figure 1b. Example of the stimuli used in the Analogy condition in the second measurement after adding the fourth object.

In this experiment the stimuli were presented in a triangle configuration. Different sets of stimuli were used in every trial with different spatial arrangements and absolute sizes as well as different animals. The objects from the child's set were covered with white boxes of equal size (Figure 2 and Figure 3, correspondingly).

Figure 2. Example of the stimuli used in the Analogy condition in the first measurement before adding the fourth object. The experimenter's set could be seen in the upper side of the table.

Figure 3. Example of the stimuli used in the Analogy condition in the second measurement after adding the fourth object, which in this case is smaller (weaker) than the smallest one.

Procedure

Each child participated in two individual experimental sessions. Each session included three training trials and five test trials. In the training trials the experimenter gave the child feedback in order to make sure that he/she correctly understood the instruction.

The instruction for the Control group in the test trials of the first measurement session was (in Bulgarian language):

"I have three bears and you have three bears. Out of these two of my bears this is stronger than this one (pointing to the biggest and the medium bear in the experimenter's set), and from these two of my bears this is stronger than this (pointing to the medium and the smallest bears from her set). Out of these two of your hidden bears, this one is

stronger than this one, and this one is stronger than this one. Please tell me, where is your strongest bear hidden?"

The instruction for the second measurement for the Control group had two versions depending on whether we added a stronger or a weaker fourth animal. The first one was as follows:

"Now close your eyes because I will make a trick. Now look, I added another bear to my animals which is stronger than this one (pointing to the formerly biggest animal from her set). I also added another bear to your animals. The new bear is hidden under this box and now this bear is stronger than this one (pointing to the formerly biggest animal from the child's set). Now, please tell me where is your strongest bear hidden?"

The second version for the Control group in the second measurement was the same except the fact that the fourth added animal was weaker than the weakest one.

The corresponding instruction for the Analogy group in the test trials was the following:

"I have three bears and you have three bears. Out of these two of my bears (pointing e.g. to the biggest and the medium bear in the experimenter's set) this one is stronger than this one and I will put this draw-bar in such a way that the stronger bear could pull the weaker one. Out of these two of your hidden bears, this one is stronger than this one. Please, put this draw-bar in such a way that the stronger bear could pull the weaker bear. Now, out of these two of my bears (pointing e.g. to the medium and the smallest bear from the experimenter's set) this one is stronger than this one and I will put the draw-bar in such a way that the stronger bear could pull the weaker one. Out of these two hidden bears this is stronger than this. Please, put this draw-bar in such a way that the stronger bear could pull the weaker one. Now look, my bears look like a train in a turn and your bears look like another train in a turn. Please tell me where is your strongest bear hidden?"

The instruction for the two versions of the second measurement for the Analogy group was the same except that the added fourth animal was connected to the smallest or the biggest animal by a new draw-bar. We randomized the sequence in which the fourth strongest or weakest animal was added. An important fact about this experiment was that the child had never seen the objects in his/her set and it was not possible to solve the task by remembering the absolute sizes of the stimuli.

Participants

49 children were studied in this experiment. 25 of them formed the Control group, 24 formed the Analogy group.

The average age of the children was 4 years and 5 months ranging from 4 years and 1 month to 4 years and 11 months.

Results and discussion

The data are presented in Figure 4. The mean for the Control Group in the three objects trials is 2.56 (out of 5), and in the fourth objects trials is 2.04. There is a slight decrease in this group. The corresponding means for the Analogy group are 3.46 for the three objects trials and 3.58 for the four objects trials. The chance level for the three objects trials is 1.66 and for the four objects trials is 1.25.
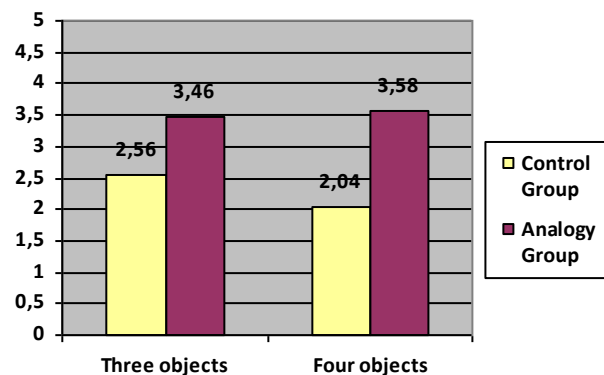

Figure 4. Mean scores (which vary from 0 to 5) for each measurement for each group. There is a clear Analogy effect $F (1, 47) = 12.478$, partial $\eta^2 = 0.21$, $p = 0.001$

A repeated measures ANOVA has been run with within group factor the number of objects and between group factor the presence or absence of analogy. There is an effect of the Analogy manipulation and the performance of the children in the Analogy group is significantly better than the performance of the children in the Control group ($F (1, 47) = 12.478$, partial $\eta^2 = 0.21$, $p = 0.001$). Pair-wise comparison shows that there is significant difference between the two groups in both the first measurement with sets of three objects ($F(1,47)=4.142$; $p=0.047$) and in the second measurement with sets of four objects ($F(1,47)=22.548$; $p<0.001$).

Analysis of the within subject factor shows that there is no difference between the two measurements of each child ($F(1,47)=1,267$; $p=0,266$) which means that there is no significant improvement or decrease of the results of each child after adding the fourth object. Children are equally good in solving transitive inference tasks with three and four objects. The interaction between the two factors is also not significant $F(1, 47)=2.547$, $p=0.072$.

Additional analysis shows that there is a significant difference between the children's performance in each measurement and the corresponding chance level in both groups. The difference between first measurement and chance level of 1,66 in the Control group is $T(24)=7,709$ $p<0,001$, a similar difference could be found when comparing the second measurement with the chance level of 1,25 in Control group ($T(24)=12,134$; $p<0.001$). For the Analogy group the results are similar ($T(23)=11,985$; $p<0.001$) when comparing the score of first measurement with the chance level of 1,66, and ($T(23)=12,716$; $p<0.001$) when comparing the score of the second measurement and chance level of 1,25). These results could be interpreted that in both measurements in both groups children are significantly better than the chance level in solving the transitive inference tasks.

General Discussion

The results showed that both groups are significantly better than the chance level in both measurements which means that children are able to solve transitive inference

tasks to some degree. These findings are consistent with the results of Bryant and Trabasso (1971) and Pears and Bryant (1990) which showed that young children could solve transitive tasks when memory limitations were overcome or when the relations were visible for the child at the moment of decision making.

We can also claim that children showed an understanding of relativistic nature of relations because the results from the second measurement are also significantly better than the chance level in both groups. In three of out of 5 trials one and the same object is "stronger than" in the first measurement and is "weaker than" in the second measurement. So, the child had to reverse the answer in order to respond correctly. Children succeeded to overcome this difficulty and demonstrated an understanding that relations are not object's attributes and have a relative nature.

Most importantly, there is a main effect of the Analogy manipulation and children in the Analogy condition demonstrated significantly better performance than the children in the Control condition (both with three and four objects). This shows that analogy making could play an important role in accumulating experience and development of the transitive reasoning ability. This is in accordance with Halford's (1993) claim that deductive reasoning development is based on analogical reasoning and with Kokinov's (1990, 1992) proposal that the same mechanisms could underlie both types of reasoning.

How can we explain the specific effect of the train analogy in this experiment? One possible explanation is that children know that the strongest car that pulls all other cars in the train is the locomotive which is the first wagon in the train. Thus when asked "Where is the strongest bear hidden?" they think of the configuration of boxes as a train and try to find where is the locomotive. Then they use the draw-bars in order to determine where the locomotive is. This explanation relies of their common knowledge of trains and the causal model of its movement. A second possible explanation is that children are mapping their hiding boxes to the experimenter's set of visible animals; they determine perceptually which the strongest visible animal there is and map it back to the strongest animal hidden in their corresponding box. The question is why children cannot do this in the control condition, and the answer could be that the analogy with the train and the visible draw-bars in both "trains" help children in doing the mapping. This is in accordance with the results obtained in an earlier experiment showing that the train analogy and the use of draw-bars help children make the analogical mapping (Mutafchieva & Kokinov, 2007b). Finally, it could also be argued that the analogy does not play any role here and simply the presence of the draw-bars in both sets makes is easier for the children to do the mapping and find which box corresponds to the strongest animal in the experimenter's set. Although we cannot rule out this possibility, we believe that this is not very probable since in this earlier experiment (Mutafchieva & Kokinov, 2007b) the results from a

condition with draw-bars without the introduction of the train analogy did not help children in doing the analogical mapping and this group was indistinguishable from the control group. Thus it seems that the draw-bars become meaningful and usable for the children only after they are considered as part of the causal model of the train.

It is also possible that the draw-bars simply facilitated children in remembering the relations between the four objects and these physical representations were visible for the child at the moment of decision making. As explained above, however, we believe that the draw-bars alone will not do the tick. Especially since the children in both groups seemed to successfully remember the premises which could be seen from their answers to the control questions asked. Of course, we need further experimentation in order to distinguish between all these (and other) explanations.

The main conclusion for the moment is that children in our experiment demonstrated an ability to make transitive inferences and understanding of relativistic nature of relations. In addition, the train analogy in combination with draw-bars as physical representations of relations facilitates this children's ability to make transitive inferences. These first data suggest that analogy could be an effective mechanism for learning to do transitive inferences supporting Halford's theory that deductive reasoning development is based on analogy-making development.

Acknowledgments

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