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Finding a Bigger Fish Bowl: Higher Difficulty Helps Transitive Inferences

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Abstract

The current study looks at preschoolers' ability to discover higher-order patterns spontaneously, without being explicitly taught to do so. The higher-order pattern of interest was the degree of transitivity among the relations of three arbitrary dimensions. Preschoolers and adults were taught two relations (i.e., A = B; B = C), and they were asked to guess the third relation (i.e., between A and C). In each case, a relation was a perfect correlation between two arbitrary relations (e.g., heavy = large). The crucial manipulation pertained to how difficult it was to learn the two relations. The two relations either matched in direction (which was conceived as low learning difficulty), or they had opposite directions (which was conceived as high learning difficulty). Our prediction was that the higher-order pattern of transitivity becomes apparent when learning difficulty is high. The argument is that a local mismatch makes it difficult for children to focus merely on the isolated relations, and thus sets the stage for higher-order insights. Results confirm our hypothesis, both for preschoolers and adults. Participants were more likely to engage in higher-order transitive reasoning in the case of a local mismatch between the to-be-learned relations than in the case of a local match.

Keywords: learning; preschoolers; reasoning

Introduction

It is commonly believed that young children learn best when the content is broken down into 'digestible' pieces of information. The implicit expectation is that the pieces of information are combined into a whole later on, when the child is thought to be cognitively ready. For example, to teach children about an overarching principle, say in physics, one might introduce children to the constitutive parts of the principle first. When ready, the child might then put the pieces together and infer the overarching principle.

Basic-level research casts doubt on this logic, however. In particular there is evidence that children have difficulty combining pieces of information into larger units (e.g., Morris & Sloutsky, 2002; Ruffman, 1999). Therefore, teaching them piece-meal information might not lead to the desired success. Take for example a context in which participants are presented with the three physical dimensions size, loudness, and grayness (Smith & Sera, 1992). The task is to relate each dimension to the next, such as to determine whether something small goes with something loud or quiet, whether something loud goes with something dark or light, and whether something dark goes with something big or small. Children at preschool age had no difficulty relating the dimensions in a consistent way (e.g., if they decided that small goes with light, they also related dark with big). However, preschoolers were not constrained by the higher-order transitivity among these relations. Children believed, for example, that a big object was related to a loud sound (A = B), that the loud sound was related to the light gray (B = C), and that the light gray was related to the small object (C = not A). Figure 1 shows these three relations in schematic form. While they are normatively possible, they do not respect transitivity.

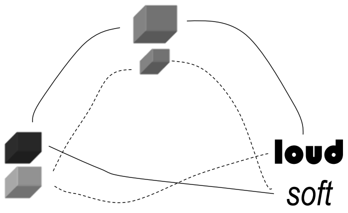

Figure 1. Representation of three features relations (combining two dimensions each) that lack transitivity among each other.

There is another reason why a piece-meal teaching approach might not work. Children not only fail to combine pieces of information into a desired higher-order structure, they impose an incorrect structure, ignoring pieces of information that conflict with it. In other words, children might fail altogether to learn a piece of information if it does not match with other beliefs they might hold. Consider, for example, children's beliefs that heavier objects sink faster in water than lighter objects. When this belief is somehow elicited in a teaching protocol, children will have difficulty learning that small objects sink faster than large objects (Kloos, 2007). There is nothing particularly difficult about the latter volume-speed relation, and children can easily learn it if it is the only thing children think about. But as soon as mass is varied in a salient way, children impose an overarching belief that mass and volume correspond in their effect. They believe that, if heavy objects sink fastest, large objects should sink fastest too.

If learning the individual parts of the whole does not necessarily set young children up to spontaneously discover an overarching principle, and if young children might even fail to learn individual parts, what could help them learn higher-order patterns?

To address this question, we used a transitive-inference task similar to the one used in Smith & Sera (1992) described. While transitive inference is not a concept commonly taught to children, it is seen as a basic reasoning process that might underlie all learning of higher-order structure (Inhelder & Piaget, 1958). Furthermore, young children are not incapable of making a transitive inference (e.g., Adams, 1978). When preschoolers were taught the length relation between five sticks in a series (e.g., stick A is taller than stick B, stick B is taller than stick C, and so on), they were able to incorporate a new stick into the series and guess its relative size, integrating the sticks into one continuous dimension.

Of course, Adams' transitive-inference task on how sticks relate to each other in their lengths differs from Smith & Sera's transitive-inference task on how the alignment of poles respects higher-order Gestalt. Most notably, transitivity pertains to a logical necessity in the former case, but not in the latter case. If Stick A is larger than Stick B, and Stick B is larger than stick C, then stick A has to be larger than stick C – by logical necessity. Conversely, if big goes with loud, and loud goes with dark, it is not logically required that dark goes with big. Nevertheless, despite these differences in context, findings from Adams (1987) shed light on what it is that might help children discover the higher-order pattern of transitivity.

In particular, preschoolers in Adam's study were more likely to make a transitive inference when the length differences between the sticks were small (approximately 1 cm.). The small difference in length might have allowed children to think of the series as a whole, rather than to focus on each pair individually if the length differences were larger. Based on the findings, we predict that children are more likely to attend to a higher-order pattern when a narrow focus on an isolated pattern hinders learning of isolated parts. In Adams' (1978) transitive-inference task, a 1cm length difference between adjacent sticks made it difficult to narrowly focus on isolated sticks (none of them stuck out as particularly long or particularly small).

Similar arguments have been made in mathematical reasoning, when 11-year-olds spontaneously discovered a mathematical rule after being presented with individual instances (Kaminski, Sloutsky, & Heckler, 2009). Learning was markedly improved when individual instances were maximally abstract, possibly because it made it difficult for children to sustain a local focus on the separate instances. In the current paper, we apply this idea to transitive inferences.

In particular, we adapted a version of the Smith and Sera (1992) task that involved relations between three physical dimensions (size, shading, and depth). Given that dimensions are polar (they have a 'more' pole and a 'less' pole), a relation can be considered positive or negative. For example, 'big' aligning with 'dark' is a positive relation, while 'big' aligning with 'light' is a negative relation[1]. Transitivity exists when the three relations are congruent among each other. For example, in a congruent set, 'big' is aligned with 'dark' (A = B), 'dark' is aligned with 'deep' (B = C), and 'deep' is aligned with 'big' (C = A). Figure 2 shows the congruence among these relations graphically.

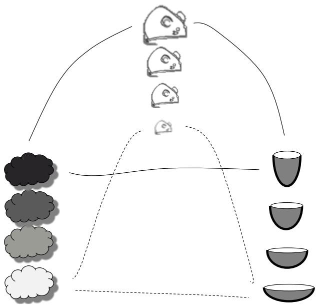

Figure 2. Representation of the three feature relations that are congruent among each other.

Preschool children were taught two of the relations (e.g., how size relates to darkness and how darkness relates to depth), and they had to guess the third relation (e.g., how size relates to depth). Adults were included for comparison purposes.

We tested the idea that children might attend to a higher-order pattern of transitivity in situations in which focusing of isolated parts was hampered in the task. The crucial manipulation was whether the two to-be-learned relations matched in direction or not. Relations that matched in direction were either both positive (e.g., 'big' goes with 'dark', and 'dark' goes with 'deep'), or they were both negative (e.g., 'big' goes with 'light', and 'light' goes with 'deep'). And for relations that did not match in direction, one was positive and one was negative (e.g., 'big' goes with 'dark', and 'dark' goes with 'shallow').

Our reasoning was that children could easily learn relations that match in direction. Children might therefore merely focus on learning the isolated relations, without regard for the higher-order pattern of transitivity. Conversely, children should have more difficulty learning the two relations of opposite direction. As a result, they might be more likely to spontaneously integrate the two into the higher-order patterns of transitivity.

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[1] Note that the 'more' pole is ambiguous for shadings (more grey vs. more white), and for depth (deeper vs. wider). On an absolute level, it is therefore arbitrary whether a relation is considered positive (big = more gray) or negative (big = less white). However, the chosen 'more' pole was always labeled as such (i.e., darkest; deepest) resulting in the prescribed direction of the relation.

Method

Participants

A total of 63 children, aged 4 to 5 years (*M* = 5.0 years, *SD* = 3.6 months) were recruited from daycares and elementary schools located around the Cincinnati, OH and Northern Kentucky areas. Three children were tested and excluded from the experiment because they did not meet the learning criterion (see Procedure), and five children did not finish due to loss of interest. In addition, we tested 60 undergraduate students (*M* = 21.4 years, *SD* = 5.7 years), recruited from the University of Cincinnati, in return for class credit.

Materials

Materials were pictures of four cartoon mice, four clouds, and four bowls, presented on a computer screen. Mice differed in size (from 1 to 4 cm), clouds differed in achromatic color (from the lightest shade of gray to the darkest gray), and bowls differed in depths (from shallow to deep). Figure 2 shows the four pictures of each element. The resulting relations are between mouse size and cloud darkness (MC), mouse size and bowl depth (MB), and between cloud darkness and bowl depth (CB).

Relations between features were labeled either positive or negative, depending on how the poles of features size, darkness, and depth were introduced. For example, for a positive mouse-cloud relation (MC+), the bigger mouse was paired with the darker cloud; for a negative mouse-cloud relation (MC-), the bigger mouse was paired with the lighter cloud.

Design

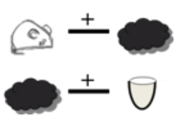
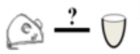
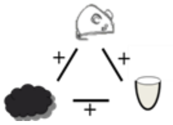
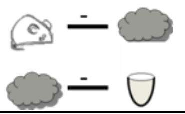
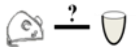
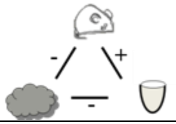
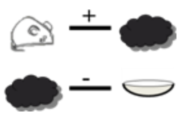
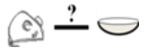
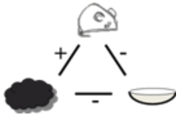
There were three conditions that differed in the direction of the relations presented to participants. Participants were taught two relations: two positive relations (e.g., MC+CB+) in the Plus-Plus condition, two negative relations (e.g., MC-CB-) in the Minus-Minus condition, or a negative and a positive relation (MC+CB-) in the Plus-Minus condition.

Table 1 shows, in schematic form, how the relations were combined to create the three different conditions. The first column contains the two to-be-learned relations participants were presented with. The second column shows the relation that participants were asked to guess. Finally, the last column shows the expected direction of the third relation if participants pay attention to transitive congruence. For example, if participants learned a positive cloud-bowl relation (CB+) and a positive mouse-cloud relation (MC+), then the direction of the third relation is expected to be positive as well.

Procedure

The cover story involved an explorer, Toto, who found a machine on a far-away planet. The machine was said to transform things. In particular, participants were told that this machine transformed objects: “If something is put it on one end, something completely different comes out on the other end.”

Table 1: How the combinations of the relations create each condition.

To-be-Learned Relations	To-be-Inferred Relation	If congruent…
Plus-Plus (two positive relations)		
		
Minus-Minus (two negative relations)		
		
Plus-Minus (one positive and one negative relation)		
		

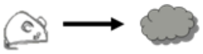
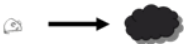
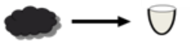
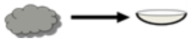
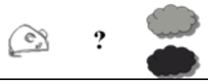
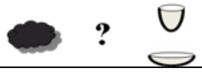
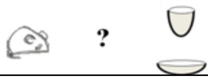
The next step was to introduce the objects that could go into the transformer. Six pictures of differently-sized mice were placed in front of the participant in random order. The difference in dimension was pointed out (e.g., ‘See how some mice are big and some are little”), and participants were asked to point to the biggest mouse. Help was provided as needed. The chosen picture was moved to the side, participants had to point to the next biggest mouse, which again was moved to the side, and so on. Next, participants were presented with six pictures of differently colored clouds, and they were asked to order them from darkest to lightest. Finally, participants were presented with six pictures of bowls and the required ordering was from deepest to most shallow. Children and adults had no difficulty completing this task, suggesting that they could focus on the dimensions in question.

To prepare participants for the learning task, the experimenter provided the following information, accompanied by pictures on the computer:

> “A mouse will either turn into a cloud or a bowl, a cloud will turn into either a mouse or a bowl, and a bowl will turn into either a mouse or a cloud. Sometimes the biggest mouse will turn into the darkest cloud, and sometimes the biggest mouse will turn into the lightest cloud. Sometimes the darkest cloud will turn into the deepest bowl, and sometimes the darkest cloud will turn into the shallowest bowl. Sometimes the deepest bowl will turn into the biggest mouse, and sometimes the deepest bowl will turn into the smallest mouse. Toto is very confused and doesn’t know what’s going on. But he made some movies for us showing us what the transformer is doing. Can you help him figure it out?”

The experiment proper started immediately and had two phases: a demonstration phase and a testing phase (see Table 2). During demonstrations, participants watched a set of movies that conveyed the feature relations. For each movie, two transformers were displayed above each other, in the middle of the screen. Two objects entered simultaneously on one side of each transformer, and another two objects came out simultaneously on the other side of the transformer. For example, a big mouse and a small mouse each entered a transformer, and a dark and a light cloud each come out on the other end.

Table 2: The experiment phases in step-by-step form.

Phase 1: Demonstration	
Relation 1	
3 movies Pretest: 4 trials	
3 movies Pretest: 4 trials	
Relation 2	
3 movies Pretest: 4 trials	
3 movies Pretest: 4 trials	
Phase 2: Testing	
Learning Trials	
Relation 1: 4 trials	
Relation 2: 4 trials	
Inference Trials	
Relation 3: 4 trials	

To convey a relation, there were two sets of three movies, each followed by pre-testing to gauge initial learning. Movies pertaining to the same relation differed in the way items were combined with each other. The order in which movies were presented was randomized across children. Pre-testing started with a reminder of the relation presented during the set of movies. For example, if the movies showed a bigger mouse turning into a darker cloud, the experimenter explained: “The biggest mouse will always turn into the darkest cloud.” Four pre-testing trials followed, each asking what an object turned into. For example, if the movies showed a bigger mouse turning into the darker cloud, the question was: “What cloud did the bigger mouse turn into?” Participants had to perform consistently, either correct or incorrect, on at least three of the four trials. They were excluded otherwise.

After participants watched two sets of movies for one relation and then two sets of movies for the second relation, the testing phase started, with the following instructions:

> “I think you know everything there is to know about the transformer. But just to make sure, Toto wants to ask you a few more questions.”

Then four trials per relation were presented. The learning trials, for the first and second relations, were identical to the pre-testing trials presented earlier. The inference trials came last, following the same format as the other trials. Participants were asked to make a guess about the third relation that was not presented. For example, if the mouse-bowl relation was never shown, the experimenter would ask “what will the big mouse turn into?”

The demonstration phase lasted about 10 minutes, with the introduction and testing phases each lasting another 2-3 minutes. Overall, the experiment lasted around 15 minutes.

Results

In a preliminary analysis, we looked at children’s learning of the two relations presented to them. For each participant, we calculated an average proportion-correct score across the eight learning trials. A 3 by 2 between-subjects ANOVA was conducted, with condition (Plus-Plus, Minus-Minus, Plus-Minus) and age (preschoolers, adults) as the factors. It revealed a significant effect of age, $F(1,117) = 31.27$, $p < .01$, in that adults performed better on learning trials ($M = .96$) than preschoolers ($M = .77$). There was also a difference in condition, $F(2,117) = 5.49$, $p < .01$, suggesting that participants had some difficulty learning the relations presented to them. However, there was no interaction with age and condition, $F < 1.85$, $p > 0.16$. Figure 3 shows the degree of learning (represented as mean % correct), as a function of age group and condition.

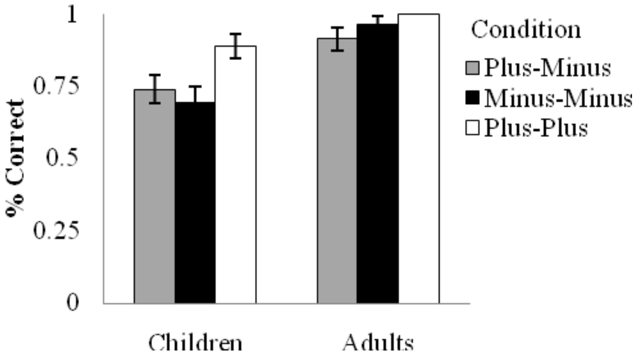


Figure 3. Mean performance correct on learning trials (to test the degree of learning), as a function of age and condition. Standard errors are shown as error bars.

To determine if participants were congruent in their inferences about the third relation, we considered only those participants who performed consistently on each set of four learning trials per relation. ‘Consistent’ here means either correct performance on at least three learning trials of a relation, or incorrect performance on at least three learning trials of a relation. Eighteen children (29%) and 4 adults (7%) did not meet this criterion and were not included in the transitivity analysis. Of the included participants, 13 of the children and 3 of the adults performed consistently incorrect on one set of learning trials, and nobody performed consistently incorrect on both sets of learning trials.

If children make congruent inferences, then the inferred relation should be negative if one of the learned relations is positive and the other is negative. The inferred relation should be positive if the learned relations are either both negative or both positive. To what degree did participants' inferences follow this pattern across the four inference trials? Figure 4 shows participants' transitivity performance as a function of age and condition. A score of 1 means that performance was congruent on all four inference trials, while a score of 0 means that performance was incongruent on all four inference trials. As can be seen in the figure, both children and adults were more likely to give congruent answers in the Plus-Plus and Plus-Minus condition than the Minus-Minus condition.

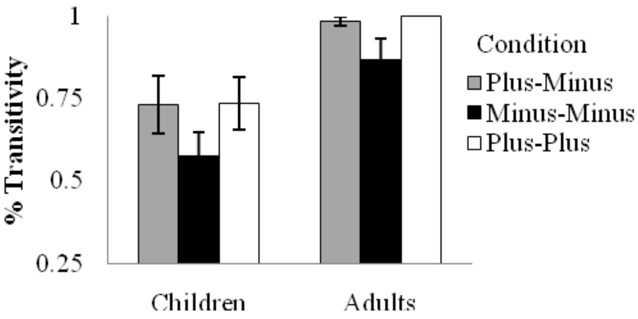


Figure 4. Mean proportion transitive inferences, as a function of age and condition. Standard errors are shown as error bars.

The transitivity scores were submitted to a 3 by 2 between-subjects ANOVA, with conditions (Plus-Plus, Minus-Minus, Plus-Minus) and age (preschoolers, adults) as factors. There was a significant effect of age, $F(1,95) = 30.11$, $p < .01$, with adults having higher transitivity scores ($M = .95$) than children ($M = .69$). More importantly, there was a significant effect of conditions, $F(2,95) = 3.59$, $p = .03$. There was no significant interaction, $F < .05$, $p > .95$, meaning that this pattern stayed the same for both children and adults. For both children and adults, guesses were transitive in the Plus-Minus and Plus-Plus conditions, but less so in the Minus-Minus condition. Learning score was uncorrelated with transitivity score.

Summary & Discussion

Our prediction was that children would be more likely to attend to the higher-order pattern of transitivity when the learning of the local elements (the single relations that make up the whole) did not afford a narrow focus. Learning two positive relations did not interfere with a local focus: children could pay attention to only one of the two relations and still be able to learn the second one (because the direction matched). The same was true for learning two negative relations: focusing locally on one negative relation did not hinder (and might have even helped) the learning of the second negative relations. But when children were asked to learn a positive and a negative relation, a local focus on a single relation hindered learning.

Results support our prediction – with a twist. Inferences of children in the Minus-Minus condition were less transitive than of children in the Plus-Minus condition. And the lower transitivity performance was not related to the participants' learning scores (i.e., the degree of transitivity of the guessed relation cannot be explained by the degree of learning of the two presented relations). This finding is consistent with our hypothesis: when children had to learn non-matching relations that hindered an overly local focus, the overarching pattern of transitivity was likely to emerge. Importantly, the patterns of transitivity appeared spontaneously for an age group that is commonly known for having difficulties with transitive inferences.

Adults were more likely to make a transitive inference than children. However, they were also affected by the learning manipulation. Transitivity was lower in the Minus-Minus condition than the Plus-Minus condition. As was found with preschool children, when single relations were difficult to learn with a narrow focus on each separate relation, adults spontaneously applied the higher-order transitivity to the relations.

A surprising finding pertained to performance in the Plus-Plus condition. We predicted transitivity to be low in this condition, because the two to-be-learned relations matched in direction, and thus afforded a local focus. Nevertheless, children and adults made higher-order transitive inferences when asked to guess the direction of the third relation. What could explain this performance?

A closer look at the specifics of the Plus-Plus condition might shed light on participants' inferences. Recall that two positive relations are congruent with another positive relation. If 'big' goes with 'dark' (positive), and 'dark' goes with 'deep' (positive), then 'deep' should go with 'big' (positive). But guessing a positive relation might be a default (cf., Inhelder & Piaget, 1958). Therefore, participants might have guessed a positive relation in this case with little regard to transitivity among all three relations.

If this is the case, participants' bias toward a congruent set of relations in the Plus-Minus condition is even more impressive evidence of transitive inference. In the case of a positive and a negative relation, the congruent third relation is negative (e.g., if 'big' goes with 'dark', and 'dark' goes with 'shallow', then 'deep' should go with 'little'). Thus, to make a congruent guess, participants (including preschool children) had to go against a default of guessing a positive relation and guessed a negative relation. Note that this interpretation of the results needs to be qualified until we gain a better understanding of how children match the poles a priori.

Taken together, the results suggest that higher-order transitivity is an emergent property, employed as a means of reducing learning complexity. With higher complexity of individual elements, a local focus was compromised, helping children to note the larger whole. In future studies, it may be useful to follow up with different conditions, such as other cover stories or other objects. It remains to be seen if these claims hold across different domains.

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