# Encoding of Elements and Relations of Object Arrangements by Young Children

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**Abstract**

Two experiments investigate the ability of four-year-old children to spontaneously process relations as well as elements in an immediate recognition task. The experiments also test predictions of a model proposed to account for differential processing of elements and relations. Both experiments used a two-item forced-choice task. In each experiment, children accurately recognized the target, regardless of whether distracter items included different elements or different relations. The results of these experiments suggest that young children do spontaneously process relations as well as elements. These findings in conjunction with earlier results also suggest that more pronounced privileged processing for elements may not arise from initial encoding, but rather from events which occur later in processing such as recoding to a long-term memory representation, or retrieval from long-term memory.

## Introduction

In order to interact with and understand our world, we must be able to identify the things we encounter, as well as the relationships between them. We must be able to process and recognize individual items, or elements. Also of fundamental importance, we need to make sense of elements by organizing them and recognizing the underlying relations between them.

Recognizing relations between elements is fundamental to many tasks we undertake, such as mathematics, analogical reasoning, problem solving, and reading. In mathematics, we need to recognize that problems with very different elements are often linked by common relations. For example, understanding how (5 x 3) is equivalent to (5 + 5 + 5) helps us understand the relation between other multiplication and addition problems and allows us to solve new problems more easily.

What is considered to be an element in one context may be a relation in another. Relations between elements in reading allow us to comprehend what an author is trying to convey. If we were to focus only on the elements in reading, we would process words or letters alone and find the overall meaning difficult to grasp. By recognizing the relations between letters, however, we comprehend words; by recognizing the relations between words, we comprehend sentences.

There is much evidence that elements are processed faster than relations across different task types (Goldstone & Medin, 1994; Ratcliff & McKoon, 1989; Sloutsky & Yarlas, 2000). Given this, Sloutsky and Yarlas (2002) propose that there might be invariances in processing elements and relations that are found across different domains. To further test this idea, they investigated processing of elements and relations in a conceptual domain (i.e., logical relations) and in a spatial domain (i.e., object arrangements). They found that though absolute processing time and accuracy are affected by the specific computations a task requires, relative processing time and accuracy are equivalent across these domains. That is, elements are processed more accurately than relations and elements are processed prior to relations across domains.

To account for the invariances found in processing elements and relations across domains, Sloutsky and Yarlas (2002) have proposed a general model of processing that occurs when a series of elements are bound into a relation and are subsequently recalled. The model consists of an encoding phase and a retrieval phase. In the encoding phase, items are initially detected and identified. Next, elements and relations are bound together to form a representation in working memory. Finally, a memory trace or category abstraction is formed and stored in long term memory.

The retrieval phase is initiated when an element or relation is subsequently encountered. It is similar to the encoding phase in that it requires the encountered item(s) to be detected, identified, and bound into a new representation. This representation, however, is then compared with an "echo" retrieved from long term memory and a decision and response are made with respects to whether the initial and subsequent items are the same or different.

Sloutsky and Yarlas (2002) conducted a series of experiments to determine which stage of processing is implicated in the differential processing of elements versus relations. In two of their experiments, they eliminated all processing steps past the first encoding. That is, the need for forming a memory trace to be stored in long-term memory, and consequently, the need for retrieval, was eliminated. This was done by using an immediate recognition task in which presentation of a target was followed immediately by presentation of a comparison item. One task involved recognition of target propositional arguments; the second task involved recognition of target object arrangements. Sloutsky and Yarlas found that, unlike delayed recognition tasks, the immediate recognition task resulted in high accuracy for both elements and relations. They concluded that difficulty of processing relations may stem from retrieval rather than from encoding.

The goal of this research is to test this conclusion with young children. Note that the Sloutsky and Yarlas work (2002) was done with adult participants. Research on processing elements and relations in children indicates that young children (ages 4-6) are less likely to process relations than older children and adults (Gentner & Toupin, 1986; Kotovsky & Gentner, 1996; Yarlas, 2001; Yarlas & Sloutsky, 2001). However, based on Sloutsky and Yarlas' findings, it seems plausible that under simplified memory demands, young children would be able to process relations that they fail to process under conditions where the memory demands are greater. The reported research tests this hypothesis by using two relations that adults handle differentially (Sloutsky & Yarlas). One of these relations is a symmetrical relation with an A-B-A pattern arrangement; adults readily processed this relation even in a delayed recognition condition (Experiment 1). The other relation is an asymmetrical relation with an A-B-B pattern arrangement; in a delayed recognition task, adults had much more difficulty with this relation than with the A-B-A relation (Experiment 2).

Both experiments described here investigate the processing of elements and relations using simple object arrangements. The task used is an immediate recognition task where children are asked to remember a target and are then shown two test items and are asked to decide which is the same as the target.

## Experiment 1

The purpose of Experiment 1 was to determine whether young children spontaneously process relations as well as elements in an immediate recognition task. In Experiment 1, simple shapes were presented as target items in an A-B-A relation.

### Method

**Participants** Participants were 17 4-year-old children (11 boys and 6 girls, $M$ = 4.6 years; $SD$ = 0.19 years) recruited from childcare centers and preschools located in middle-class suburbs of Columbus, Ohio.

**Materials and Design** The experiment had a two-item forced-choice within-subjects design. The dependent variable was accuracy of responses. All stimuli were approximately 1.5 x 1.5 cm. Four basic shapes (square, circle, triangle, and diamond) and four primary colors (red, green, yellow, and blue) were used. The stimuli were created in Microsoft PowerPoint and the intensity of all colors was muted at 50% of normal saturation. Colors did not vary within each trial, but different colors were used across trials to help maintain the child's attention during the task.

Each stimulus item consisted of a series of three shapes. The three shapes were centered and equally spaced in an enclosed line box measuring 2.25 x 7.5 cm.

There were 12 different A-B-A target items (e.g., square-circle-square). Each target item was also presented as a test item with a foil (i.e., distracter) item. There were three types of foils; E+/R- foils, E-/R+ foils, and E-/R- foils. E+/R- foils had elements (shapes) identical to those in the target item, but they were arranged in a different relation (i.e., in an A-A-B pattern). E-/R+ items had different elements, however the relation between those elements mirrored that of the target item (i.e., different shapes in an A-B-A relation). Finally, E-/R- items had elements that were different from those in the target item; additionally, the elements were arranged in a different relation (i.e., different shapes in an A-A-B pattern). The E-/R-condition was included as a control condition to ensure that children understood the task and were paying attention.

Each target item was presented with each of the different foil types as a test item on different trials; this resulted in a total of 36 test trials.

Trials were presented on a Dell laptop computer using SuperLab Pro software (Cedrus Corporation, 1999). Responses to items were entered by the experimenter using a Cedrus RB-400 4-button response box. Reaction times began when the test stimuli appeared and were collected by the program when a response was made.

There were two different pseudo-randomized trial orders. The orders were arranged such that identical A-B-A items were not target items on consecutive trials. Also, while all shapes were the same color within a trial, no color was repeated on consecutive trials. Furthermore, the same foil type did not appear on more than two consecutive trials. Finally, the position of the correct items was counterbalanced such that on half of trials, the correct response was to the item on the left and on the other half of trials, the correct response was to the item on the right. Correct responses did not appear on the same side (e.g., left side) for more than two consecutive trials.

**Procedure** Each child was tested individually by a female experimenter in a small, quiet room at the child's daycare center. The experimenter explained that they were going to play a game in which some toys were missing and the child had to match secret codes to help find the toys.

All children completed 6 practice trial followed by the 36 test trials. In test trials, children were shown the target item and then two test items. Their task was to decide which test item matched the target item they saw at the beginning of the trial. The sequence of a typical trial is depicted in Figure 1.

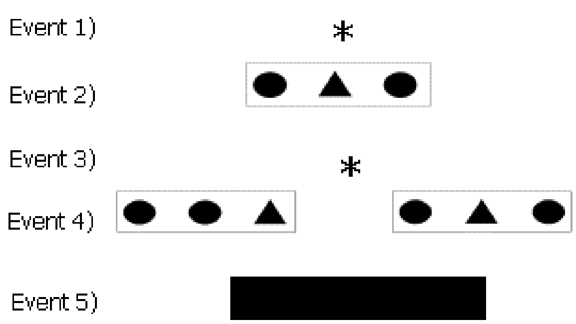


Figure 1: A typical A-B-A trial with an E+/R- foil.

Target items were presented in the center of the computer screen for 1700 ms. When the target item disappeared, an asterisk would appear in the center of the screen for 250 ms. The asterisk was followed by two test stimuli, which appeared simultaneously and were centered horizontally on the computer screen. One test stimulus was presented on the left and the other was presented on the right. The test stimuli remained on the screen until the child indicated which test item matched the "secret code" presented earlier in the trial by pointing to one of the two stimuli. The response was immediately entered into the response box by the experimenter and a blue screen appeared to mark the end of the trial. The experimenter then pressed another key on the response box and the blue screen disappeared and was replaced by another asterisk which appeared in the center of the screen for 250 ms. When the asterisk cleared from the screen, the next target item appeared. The experiment took approximately 20 minutes to complete. At the conclusion of the experiment, the experimenter told the child that he or she had found the missing toys and gave the child a small prize for helping. The experimenter then returned the child to the classroom.

## Results

If children focused on elements to the exclusion of relations, then it was expected that they would perform at chance when they were forced to choose target items which were paired with foil items that included the same elements, but different relations (E+/R- foils). If children focused on relations only, then it was expected that their performance would be at chance when relations were the same, but elements differed (E-/R+ foils). Finally, if they processed both elements and relations, then performance was expected to be accurate across foil types.

Results indicate that children were quite accurate at recognizing the target item in the test stimuli regardless of the foil item with which it was presented. A series of one-sample t-tests revealed that children were significantly above chance in accuracy for all conditions. The alpha level for all analyses was set at $p<.05$. Recall that there were 12 trials per foil type. For items accompanied by E+/R- foils, children offered correct responses 67% of the time ($M_{correct}=8.0$, $SD=2.3$), for items accompanied by E-/R+ foils, children were correct 62% of the time, ($M_{correct}=7.5$, $SD=1.9$), and for items accompanied by E-/R- foils, children were accurate 67% of the time, ($M_{correct}=8.1$, $SD=3.0$), all above chance, all one-sample $t$s > 2.8, $p$s < .02.

Repeated measures ANOVA's revealed no differences in accuracy across foil types, $F(2,32) = 1.39$, $p = .264$. That is, even when the distracters (foils) shared the same elements or the same relation as the target item, children were equally accurate in identifying the target item correctly, regardless of the level of similarity between target and foil item. Note that although no significant differences were found across the foil types, participants were slightly more accurate rejecting E+/R- foils than they were rejecting E-/R+ foils (Cohen's $d$ = 0.25). Therefore, participants were more likely to spontaneously encode relations than they were to spontaneously encode elements.

# Experiment 2

Results from Experiment 1 suggest that children as young as four do spontaneously process relations among simple stimuli. The purpose of Experiment 2 was to determine whether young children are able to process the more difficult A-A-B relation in an immediate recognition task. Recall that adults typically perform very well with A-B-A relations, but false alarm at very high rates with A-A-B relations in delayed recognition tasks (Sloutsky & Yarlas, 2002). If young children experience similar difficulties with the A-A-B relation even though task demands are reduced, it will provide evidence that preferential processing of elements occurs as early as the initial encoding.

However, if , under these simplified conditions, young children are proficient at choosing the target item regardless of whether the accompanying foil contains similar elements or similar relations, then it will provide evidence that difficulties in processing relations arise from later stages of memory operations (i.e., during recoding or retrieval).

## Method

**Participants** Participants were 14 4-year-old children (*M*=4.5 years; *SD*=.23 years; 6 boys and 8 girls) recruited from daycare centers and preschools located in the middle-class suburbs of Columbus, Ohio.

**Materials and Design** Because a few children in the first experiment were at chance even in the control condition, we deemed it necessary to modify the task instructions in order to make them simpler and clearer. The new instructions indicated that the child was going to play a matching game, where the task was to pick the item which was just the same as one just seen. The design, materials, and procedures of Experiment 2 were otherwise identical to those in Experiment 1.

## Results

Four-year-old children were again very accurate at choosing the correct test item regardless of which foil types the target stimuli were compared with. Children identified the target item correctly 68% of the time when the target and foil shared common elements, but had different relations. When the foil shared a common relation with the target, but had different elements, children chose the correct item 73% of the time, and children were accurate 80% of the time when the foil item contained different shapes in a different arrangement from that of the target. A series of one-sample t-tests revealed that these accuracy rates were all significantly different from chance: young children were accurate at choosing the correct item at a level significantly above chance when elements in the foil item matched the target, but relations did not, $t(13)=5.30$, $p=.001$; when relations matched the target item, but elements did not, $t(13)=4.55$, $p=.001$; and when the foil shared neither elements nor relations with the target item, $t(13)=6.47$, $p=.001$.

A repeated-measures ANOVA revealed significant differences in accuracy according to foil type, $F(2,26) = 3.75$, $p=.037$. Bonferroni post-hoc tests revealed significant differences in accuracy in trials involving E+/R- trials ($M = 9.6$) versus E-/R- trials, ($M = 8.1$), $p = .023$. That is, children were significantly more accurate when the shape and order information in the foil item were completely different from the target item, than they were when the foil item shared common elements with the target item. Although the difference between E+/R- ($M$=8.1) and E-/R+ trials ($M$=8.7) was not significant, $p$=.33, participants were slightly more accurate rejecting E-/R+ foils than they were rejecting E+/R- foils, Cohen's $d$=0.30. Therefore, unlike Experiment 1, in this experiment participants more ably encoded elements than relations.

## General Discussion

The fact that children in these studies were highly accurate regardless of whether distracter items contained similar elements or similar relations to the target they processed indicates that children were processing not only elements, but relations as well. If children were not processing relations, then they should have had no preference for the target item over the distracter item when test items shared the same elements, but had different relations. The fact that children were quite accurate in both experiments regardless of the distracter item present at test indicates that shared elements between stimuli was not the only criterion children used to make a positive decision. Instead, children used information from the relations as well as from elements found in the stimuli.

The results of these experiments indicate that young children are capable of readily processing relations in an immediate recognition task where the involvement of long-term memory is not necessary. That is, children as young as 4-years-old are capable of processing relations as well as elements, even when elements are similar across test items. In fact, when memory demands are low as they were in these experiments, young children are able to handle relations (i.e., A-A-B relations) which adults find difficult to manage in tasks where processing beyond initial encoding and comparison is required.

The fact that children were more accurate with the more complex relation (i.e., A-A-B) than with the less complex relation (i.e., A-B-A) appears to be a result of simpler instructions in Experiment 2 rather than a true advantage of asymmetrical over symmetrical relations. A replication of Experiment 1 with the instructions used in Experiment 2 is planned to determine if this is the case. It is important to note, however, that the instructions given in Experiment 1 should not have biased children to reject one foil type more ably than the others. This is important because looking at results from the first experiment shows that children were more accurate, not less so, when elements in the foil and target matched, but the relation was different. In the second experiment, the reverse was found. It is also important to note that these differences were not significant in either situation, although effect sizes were non-negligible. The fact that children show this reversal may indicate that under some conditions they process relations more ably than elements, whereas under other conditions they process elements more ably than relations. If confirmed, this finding would represent strong evidence that some relations are processed independently from their constituent elements..

The length of time which children in these studies had to process target and comparison items allowed them to rely solely on working memory and did not require recoding into a long-term memory representation, nor did it necessitate any subsequent long-term memory retrieval. While other studies indicate a time and/or accuracy advantage for processing elements over relations, (Goldstone & Medin, 1994; Ratcliff & McKoon, 1989; Sloutsky & Yarlas, 2000), under these less demanding memory conditions, children showed less privileged processing of elements over relations than what is found in studies with adults. The results of the current experiments support findings by Sloutsky and Yarlas (2002) that the large differences found for privileged processing of elements over relations does not appear to be a consequence of initial encoding, but rather appears to occur later in processing.

Furthermore, these studies indicate that when young children fail to process relations, it is not because they are necessarily incapable of such processing, but rather, they fail because memory demands are too great. This is similar to what happens when adults fail to process certain types of relations (Sloutsky & Yarlas, 2002). When processing requirements are reduced such that a working memory encoding is the main task demand, young children spontaneously process relations as well as elements. Further research is necessary to test the idea that increased memory demands affect elements and relations differentially, as well as to determine how the different stages of processing contribute to elements being processed faster and more accurately than relations.

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