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 indicate that previous findings of privileged processing for elements occurs during recoding of items into a long term memory code, or during a retrieval stage, but not during initial encoding.

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 and Medin, 1994; Ratcliff and McKoon, 1989; Sloutsky & Yarlas, 2000). Given this, Sloutsky and Yarlas (2002) propose that there are 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 domain of logical relations and a in a spatial domain They found that though absolute processing time and accuracy are affected by the specific computations a task requires, relative processing time and accuracy is equivalent across these domains. They found that elements are processed more accurately than relations and that 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 the Target was followed immediately by presentation of a recognition 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 samples. 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 & Yarlas' (2002) findings, it seems plausible that under simplified memory demands, young children would be able to process relations that they fail to process under conditions with greater memory demands. The reported research tests this hypothesis by using two relations that have been used in previous research with adults (Sloutsky & Yarlas, 2002). One of these relations elicited little difficulty in adults even in the delayed recognition condition (Experiment 1), whereas the other elicited significant difficulty in adults in the delayed recognition condition (Experiment 2).

Both experiments described 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

Method

The purpose of experiment one was to determine whether young children spontaneously process relations as well as elements in an immediate recognition task. In experiment one, simple shapes were presented as target items in an A-B-A relation. 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. One test item was always the same as the target item and the other was a foil item (i.e., a distracter item). There were three types of foils; there were 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).

If children were focusing 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 were focusing 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). If they were processing elements and relations, then performance was expected to be accurate across foil types.

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. Dependent variables were accuracy of responses and response times (in ms) taken to choose between items.

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. Different colors were used to help maintain the child's attention during the task, but were muted in order to assure that children did not focus on color to the exclusion of other important aspects of the stimuli, such as the shapes and their order.

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 an E+/R- foil (e.g., square-square-circle), an E-/R+ foil (e.g., triangle-diamond-triangle), and an E-/R- foil item (e.g., triangle-triangle-diamond) on different trials, resulting 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 could not be 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 could 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 could not appear on the same side (e.g., left side) for more than two consecutive trials.

Procedure Children were 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. 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

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 reveal that children were significantly above chance in accuracy for all conditions. For items accompanied by E+/R- foils, children offered correct responses 67% of the time, $t(16) = 2.82$, $p = .012$ For items accompanied by E-/R+ foils, children were correct 62% of the time, $t(16) = 3.18$, $p = .006$. Finally, when items were accompanied by E-/R- foils, children were accurate 67% of the time, $t(16) = 3.60$, $p = .002$. Repeated measures ANOVA's revealed no differences in accuracy across foil types, $F(2,32) = 1.39$, $p = .264$ and no differences in reaction time across foil types, $F(2,32) = .116$, $p = .891$. 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 and took about the same amount of time to do so, regardless of the level of similarity between target and foil item.

Experiment 2

Method

Results from experiment one suggest that children as young as four do spontaneously process relations among simple stimuli. However, in categorical recognition experiments where a categorical study-test paradigm is used, adults typically perform measurably better with A-B-A relations than they do with A-A-B relations. The purpose of experiment two was to determine whether young children experience the same difficulty with A-A-B relations in a recognition task.

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 The design, materials, and procedures of experiment two are identical to experiment one except that all target items have an A-A-B relationship instead of an A-B-A relationship. Consequently, E+/R- foils have an A-B-A relation, as do E-/R- foils. E-/R+ foils have an A-A-B relation.

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 (all tested at a .05 significance level) revealed that these accuracy rates were all significantly different from chance: young children are 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.

Reaction times to the different foil types were not significantly different, $F(2,26) = .930$, $p = .430$. Children responded equally quickly regardless of whether the target item and foil item shared common elements, common relations, or shared neither.

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.

Higher accuracy when there was no shared information (either elemental or relational), as found in experiment two, was not an unexpected finding. This is because confusion possibilities are reduced when two items or patterns are highly distinct versus when they share similarities. What is perhaps more surprising is that children were not more accurate in this condition than when distracter items contained the same elements or the same relations in experiment one. It could be that the high accuracy levels in these experiments are close to ceiling levels for this age group, and that higher accuracy levels than those observed are precluded by attentional limitations in young children. In both experiments, however, the conditions of interest, where distracters contain the same elements or the same relations were not significantly different from one another. This indicates that there was no preferential processing for elements over relations.

The results of this study indicate that young children appear to be capable of processing relations in an immediate recognition task where the involvement of long-term memory is not necessary. It appears that 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 length of time which children in these studies had to process the target and comparison items allowed them to rely solely on working memory and did not require encoding (or re-coding) into long-term memory, nor 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 no privileged processing of elements over relations. The results of the current experiments support findings by Sloutsky and Yarlas (2002) that differential processing of elements and relations does not appear to be a consequence of initial encoding, but rather appears to occur later in processing.

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 which later stage of processing results in elements being processed sooner and more accurately than relations.

Acknowledgments

This research has been supported by grants from the James S. McDonnell Foundation and the National Science Foundation (REC # 0208103) to Vladimir M. Sloutsky.

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