

## **The Effect of Attention in the Representation of Relational Information**

**Aaron S. Yarlas (yarlas.1@osu.edu)**

The Ohio State University, Center for Cognitive Science, 21 Page Hall, 1810 College Road  
Columbus, OH 43210 USA

**Vladimir M. Sloutsky (sloutsky.1@osu.edu)**

The Ohio State University, Center for Cognitive Science, 21 Page Hall, 1810 College Road  
Columbus, OH 43210 USA

### **Abstract**

The reported study attempts to specify the role of attention in the representation of relational information while controlling for knowledge. In two domains, one knowledge-lean (propositional logic) and one knowledge-independent (object arrangements), a sorting task was used to attract attention either to relational features, to elementary features, or to irrelevant features. A subsequent categorical recognition task measured representation of relational features. Results indicate that directing attention to relations increased the likelihood that relations were represented, relative to the other sorting conditions. These findings may implicate a knowledge-independent cognitive mechanism underlying representation of relational features of information.

### **Introduction**

When do people encode and represent relational information and when do they fail? For example, in object recognition it is hard to ignore the spatial relations of parts of familiar objects (e.g., that the handle of a cup is on the side, rather than the bottom), whereas the serial position of a car in a tollbooth line may or may not be noticed. The reported study attempts to specify the role of attention in representation of relational information.

Previous research in knowledge-lean domains has identified crucial differences in the processing and representation for elementary (or surface) features and relational (or deep structural) features in information. For example, a number of studies have shown that elementary features are processed prior to relational features of information (e.g., Goldstone & Medin, 1994; Ratcliff & McKoon, 1989, Sloutsky & Yarlas, 2000a). In particular, studies using a categorical recognition procedure (e.g., Sloutsky & Yarlas, 2000b) showed that participants were quite sensitive to violations of relations when given an ample amount of time to view problems in a study phase. However, when the encoding time for study items was decreased, detection of violations of elementary features in the recognition phase remained high, while detection of violations of relations dropped significantly. The preferential

processing for elements extends even to experts in a domain (Sloutsky & Yarlas, 2000a).

Furthermore, elementary features often inhibit the representation of relational features. In particular, there is empirical evidence that non-experts in a knowledge-domain focus on less important or irrelevant elementary features of problems and ignore the more important relational features of problems (e.g., Blessing & Ross, 1996; Chase & Simon, 1973; Chi, Feltovich, & Glaser, 1981; Larkin, 1983; Larkin, McDermott, Simon, & Simon, 1980; Novick, 1988; Reed, Ackinlose, & Voss, 1990; Schoenfeld & Herrmann, 1982; Silver, 1981; Simon & Simon, 1978; Yarlas & Sloutsky, 2000a).

Taken together, these findings appear to point to a knowledge-independent mechanism of processing of elements and relations. Furthermore, there is evidence implicating attention as a factor contributing to processing of relations. For example, Yarlas & Sloutsky (2000a) found that mathematics novices of different ages and abilities sorted arithmetic equations based on trivial elementary features (e.g., the magnitude of numbers in an equation, the number of elements in an equation) rather than by mathematically important relations (e.g., associativity, commutativity). However, when competing elementary features were removed, these subjects were significantly more likely to base their sorts on shared relations, indicating that they were capable of encoding these relations.

In short, previous research presents indirect evidence that elements are more salient than relations and are thus easier to attend to. The purpose of the current study is to directly examine the role of attention in the representation of relations among elements. This study uses the categorical recognition procedure, which has been established as a viable way of examining encoding and representation of features. In the categorical recognition procedure, study items all use consistent levels of both elementary and relational features. In the recognition phase, in addition to Old targets, new foils are introduced that violate either the category of elements while maintaining the same levels of relations (E-/R+) or conversely, violating the category of relations while maintaining the same levels of elements

## PAPER IN PROGRESS

(E+/R-). The degree to which these foils are correctly rejected elicits the degree to which these features were encoded and represented from the study items.

In the reported study, this categorical recognition task was preceded by an attentional manipulation. The manipulation consisted of a sorting task whose purpose was to direct subjects' attention towards either relational features (relational sorting), elementary features (elementary sorting), or irrelevant features (control sorting). If attention plays a significant role in the representation of relations, then it is expected that subjects in the relational sorting condition should be more likely to represent relations in the recognition task than subjects in the elementary sorting and control sorting conditions.

This prediction was tested in two ways. First, a group-level of analysis compared the accuracy of responses to E+/R- foils across conditions. If attention to relations does directly affect the likelihood of their being represented, then the relational sorting group should elicit fewer errors for these foils than the other conditions. Second, an individual-level analysis examined the number of participants in each group that conformed to a particular pattern of recognition responses.

### **Experiment**

#### **Method**

**Participants** Two-hundred nineteen undergraduates in an introductory psychology course at a large Midwestern university participated in this study.

**Design and Materials** The experiment included two domains (i.e., propositional logic and spatial arrangement of objects), varied between subjects. In each domain, the experiment consisted of 4 phases: (1) sorting task, (2) study phase, (3) distraction phase, and (4) recognition phase. The type of sorting was used as an attentional manipulation, and there were 3 sorting conditions varying between-subjects within each domain: (a) relational sorting, (b) element sorting, and (c) control sorting. Study materials in the propositional logic domain consisted of a set of arguments conforming to the inference rule of Modus Ponens ("If there is a 7 on the top of a card, then there is a 3 on the bottom. There is a 7 on the top. Therefore, there is a 3 on the bottom."). Study materials in the domain of spatial arrangements included simple geometric shapes arranged in an a-a-b manner (the shapes on the far left and in the middle, whereas the shape on the far right was different, such as in a graphical representation of "circle-circle-triangle"). Because materials differed across the sorting conditions and phases of the

experiment, a more detailed description of materials is given within the next section.

**Procedures** Subjects in all conditions were run individually on personal computers. All instructions and materials were presented using SuperLab Pro (Cedrus Corporation, 1997).

The experiment began with the sorting task. For the sorting task, subjects were given an example of either a propositional argument that involved Modus Ponens ("If there is a 7 on the top of a card, then there is a 3 on the bottom. There is a 7 on the top. Therefore, there is a 3 on the bottom.") or of an object arrangement (a graphic representation of an "a-a-b" relation, specifically "circle-circle-triangle"). Subjects in the relational sorting condition were instructed to notice that the exemplar contained a particular relational feature (i.e., validity, or "a-a-b"), with no explanation or definition of this relation given. Subjects in the elementary sorting condition were pointed to elementary features that would be relevant in the recognition task (i.e., that numbers in the propositional argument were less than 10, or the particular shapes used in the arrangement). Subjects in the control sorting condition were pointed to features that would be irrelevant in the recognition task (i.e., that numbers in the propositional argument were odd, or that there were 3 objects). Following this exemplar, all subjects were then given 10 sorting trials in which two arguments/arrangements were presented, with only one conforming to the condition-appropriate rule, and were instructed to choose the item that conformed to this rule. No feedback was given during these trials.

Immediately following the sorting task was the categorical recognition task. This task consisted of the study phase, the distraction phase, and the recognition phase. In the study phase, participants were presented with thirty logical propositions or thirty object arrangements, which they were instructed to memorize. These propositions and arrangements were similar to those given in the sorting task. The logical propositions all maintained a similar categorical level of an elementary feature (i.e., all numbers on cards were between 0 and 9) and all maintained a similar categorical level of a relational feature (i.e., incorporated the form of Modus Ponens). Each argument and arrangement was centered and presented in dark type on a white screen for ten seconds, with a two-second interval between each, during which only the white background was seen. Similarly, the object arrangements all maintained a categorical level of an elementary feature (i.e., used shapes and colors from among a small set) and all maintained a similar categorical level of a relational feature (i.e., followed the a-a-b pattern). All 30 arrangements in the study phase incorporated simple shapes and colors from among a set of six shapes and colors. The shapes used

## PAPER IN PROGRESS

in the study phase were circles, triangles, crosses, ovals, trapezoids, and parallelograms, while the colors included beige, light blue, gray, red, pink, and yellow. Shapes and colors varied independently. The color of each shape in each object arrangement was randomly assigned, with the constraint that no color was repeated within each object arrangement. Each object was approximately 1" by 1" in size, with approximately a .5" space between each object, and all object arrangements were centered on top of a white background. The ordering of the 30 arrangements in the study phase was randomized.

A distraction phase followed the study phase for the purpose of clearing participants' short-term memory. For the distraction task, participants were presented with ninety letters, for which they had been instructed to indicate whether the letter was a vowel or a consonant by pressing an appropriate key on the keyboard.

Following the distraction phase was the recognition phase. Participants were told that they would be presented with a number of arguments/arrangements, some of which had been presented to them earlier and some of which had not been presented earlier, and that they were to decide whether each was 'old' or 'new'. There were a total of sixty recognition items presented in the recognition phase. The order of items presented in this phase was randomized across participants. There were five categories of recognition items, with twelve exemplars for each category: (1) Old targets that had been randomly selected from among those presented earlier in the learning phase, (2) E+/R+ foils, which were new items that used elementary and relational features from the same categories as in the study items, (3) E+/R- foils, which used similar elementary features as the original items but did not use the same relation (i.e., used an invalid argument form rather than Modus Ponens, or an "a-b-b" relation, such as "circle-triangle-triangle," rather than an a-a-b relation), (4) E-/R+ foils, which used elementary features different from those used in the study items (e.g., numbers greater than 9, colors and shapes from a different set used in for the study items) but used the same relations as in the study items, and (5) E-/R- foils, which used different elementary and relational features from those used in the study items. Subjects' recognition judgments (i.e., "Old" or "New" responses) were recorded for the analysis.

### **Results and Discussion**

For the purposes of the analysis, the two domains (i.e., propositional logic and object arrangements) will be treated separately, as there are expected to be qualitative differences in the degree to which each relation is represented. The following analyses include only subjects who performed at an above-chance level

(based on the binomial test) on the sorting task, since the attentional manipulation was not effective for those who failed to do so. Data from 17 subjects were eliminated for this purpose; there were no associations between frequency of subjects who did not meet this criterion and domain or sorting condition.

For each domain, both a group-level and individual-level analysis will be conducted. The group-level analysis will involve comparing proportions of "Old" responses, collapsed across subjects, to E+/R- foils across the three sorting conditions. The individual-level analysis was focused on individual patterns of responses. In our previous work using the categorical recognition procedure, two dominant patterns (or models) of responses have emerged. Model 1, or the "elements-only model" is based on representation of only elements, and is manifested by rejection (i.e., a "New" response) of foils that violate elements (E- foils) and acceptance (i.e., an "Old" response) of foils that do not violate elements (E+ foils and Old targets), regardless of the presence or absence of relational features in foils. Model 2, or the "elements-and-relations model" is characterized by rejecting foils that violate either elements or relations (E- foils and E+/R- foils) while accepting items that do not violate these features (E+/R+ foils and Old targets). Figure 1 presents a schematic depiction of these two models. The critical foil in distinguishing between the models is thus the E+/R- foil, which is judged "Old" in Model 1 and judged "New" in Model 2.

The individual-level analysis compared the number of subjects in each condition that conform to the assumptions of each of the models presented in Figure 1. In order to classify subjects by model-based responses, the following constraints were used. A subject was classified as giving Model 1 responses if they were above chance (based on the binomial) in rejecting E- foils, and above chance in accepting E+ foils and Old targets. A subject was classified as giving Model 2 responses if they were above chance in rejecting E- foils and E+/R- foils, and above chance in accepting E+/R+ foils and Old targets. Subjects whose patterns of responses did not fit these conditions were classified as "other".

The current analyses focus on the representation of relational features as a function of attention. Group analyses will thus concentrate upon differences in responses to E+/R- foils among sorting conditions, since this is the critical foil in determining the degree to which relational features are represented. Additionally, in both domains and across all sorting conditions, subjects consistently rejected E- foils (percentage of "New" responses to these foils across conditions ranged from 89% to 99% for logic, and from 98% to 99% for object arrangements). These findings indicate that representations for elements were abundant across both

domains and all conditions. Also, in both domains and across all sorting conditions, subjects consistently accepted Old targets (percentage of “Old” responses ranged from 74% to 83% for logic, and from 89% to 91% for object arrangements) and E+/R+ foils (percentage of “Old” responses ranged from 62% to 71% for logic, and from 89% to 90% for object arrangements). In addition to showing consistency

across both domain and conditions for these items, these findings support the central assumption of the categorical recognition procedure that recognition decisions are based upon categorical memory rather than memory for specific items: subjects accept at above-chance levels new foils that maintain the same category of elementary and relational features as study items.

**Propositional Logic** A one-way ANOVA, with sorting-condition as a between-subjects factor and recognition judgments for E+/R- foils as the dependent variable, was conducted. This analysis yielded significant differences in erroneous “Old” responses to these foils across the three sorting conditions,  $F(2, 101) = 3.49, p < .05$ . The means for each condition are presented in the left side of Figure 2. Planned comparisons among the conditions indicated that the proportion of incorrect “Old” responses for E+/R- foils for subjects in the relational sorting condition ( $M = .38, SD = .33$ ) was significantly less than for subjects in the control sorting condition ( $M = .54, SD = .32$ ) and in the elementary sorting condition ( $M = .56, SD = .32$ ), both  $t_s > 2.1, p_s < .05$ . At the same time, there was no significant difference between subjects in the elementary sorting and control sorting conditions,  $t(67) < 1$ . Thus, subjects in the relational sorting condition were significantly more likely to accurately reject E+/R- foils than those in the other conditions, indicating that subjects whose attention was directed towards relations in the sorting task were more likely to represent the relational feature.

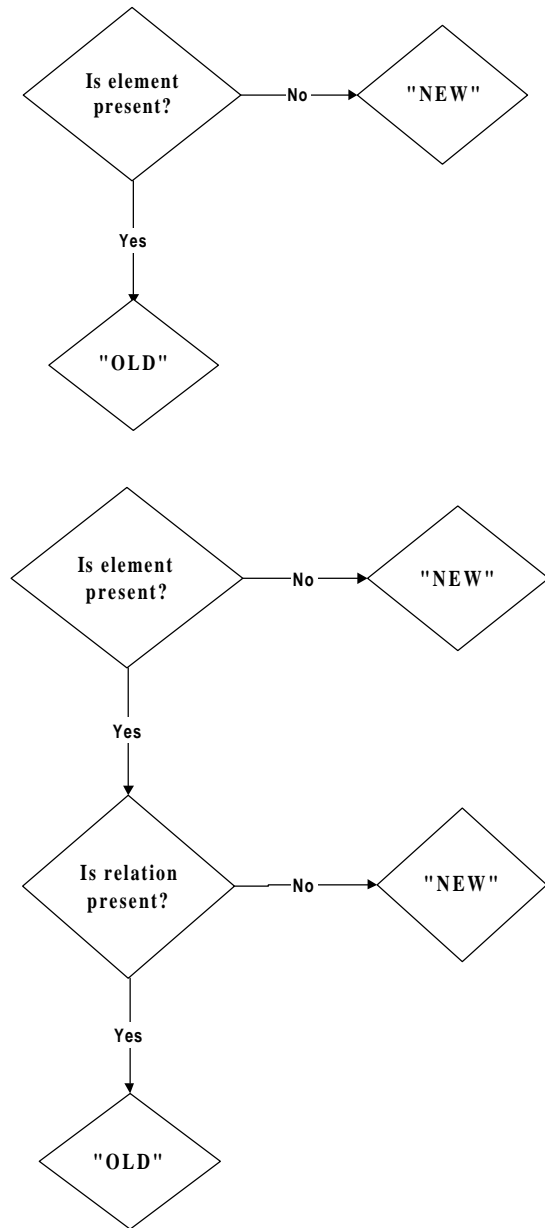


Figure 1: Models representing patterns of responses on the categorical recognition task. Model 1 (“elements-only”) is on the top, Model 2 (“elements-and-relations”) is on the bottom.

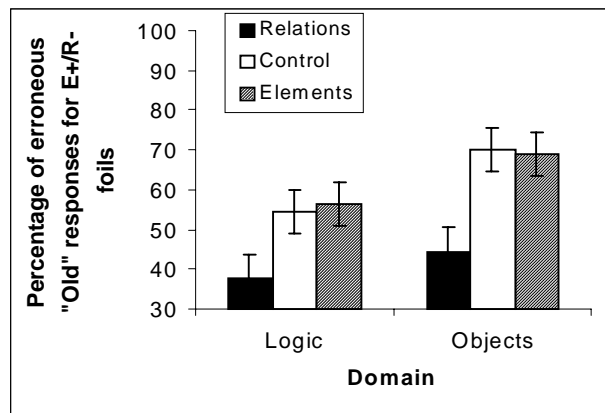


Figure 2: The percent of erroneous “Old” responses for E+/R- foils by sorting condition and domain. Error bars indicate standard errors of the means.

The individual-level analysis compared the number of subjects whose responses conformed to Model 1 (the “elements-only” model), Model 2 (the “elements-and-relations” model), or neither. These frequencies are presented in Table 1. A Chi-square analysis yielded that there was a significant association between sorting

condition and type of model used,  $\chi^2(4, N = 104) = 12.33, p < .02$ . Standardized residuals were used for paired-comparisons. These comparisons yielded that subjects in the relational sorting condition were less likely to give responses consistent with Model 1 than were subjects in the control condition,  $z = 1.7, p < .05$ , while conversely subjects in the relational sorting condition were more likely to give responses consistent with Model 2 than were subjects in the control condition,  $z = 2.9, p < .01$  (with no difference in the number of subjects who fit neither of these models,  $z < 1$ ). At the same time, there were no differences between the control condition and the elementary sorting condition in terms of model use by subjects, all  $z$ s  $< 1.4$ , all  $p$ s  $> .05$ . Subjects in the relational sorting condition were also significantly more likely to use Model 2 than those in the elementary sorting condition,  $z = 4.3, p < .001$ , although there was not a significant difference among these groups for Model 1,  $z = 1.3, p > .05$ . Overall, more subjects in the relational sort gave responses conforming to the predictions of Model 2 than in the other two sorting conditions, and were less likely to use Model 1 responses than subjects in the control condition. The findings from both the group-level and individual-level analysis thus elicit that subjects whose attention was pointed towards relations prior to the recognition task were more likely to encode and represent the relational feature of propositional logic problems than subjects whose attention was pointed to either elementary features or irrelevant features.

Table 1: Numbers of subjects in each sorting condition conforming to each model type in the propositional logic task.

Sorting Condition	Processing Model		
	Model 1	Model 2	Other
Relational	6	11	18
Element	10	1	24
Control	11	4	19

**Object arrangements** As in the propositional logic analysis, a one-way ANOVA was conducted for recognition judgments for E+/R- foils across the sorting conditions. This analysis yielded significant differences in “Old” responses to these foils across the three sorting conditions,  $F(2, 104) = 6.29, p < .01$ . The means for each condition are presented on the right side of Figure 2. Planned comparisons indicated that the proportion of incorrect “Old” responses for E+/R- foils for subjects in the relational sorting condition ( $M = .45, SD = .39$ ) was significantly less than for subjects in the control sorting condition ( $M = .70, SD = .31$ ) and in the elementary sorting condition ( $M = .69, SD = .33$ ), both  $t$ s  $> 2.9, p$ s

$< .01$ . At the same time, there was no significant difference between subjects in the elementary sorting and control sorting conditions,  $t(68) < 1$ . Thus, as for propositional logic, subjects in the relational sorting condition in this domain were significantly more likely to accurately reject E+/R- foils than subjects in the other two conditions, again indicating that these subjects were more likely to represent the relational feature.

As for propositional logic, the individual-level analysis for object arrangements compared the number of subjects whose responses conformed to the decision models. These frequencies are presented in Table 2. A Chi-square analysis yielded that there was a significant association between sorting condition and type of model used,  $\chi^2(4, N = 105) = 17.8, p < .002$ . Comparison of standardized residuals across conditions indicated that subjects in the relational sorting condition were significantly less likely to give responses consistent with Model 1 than were subjects in the control condition,  $z = 3.0, p < .01$ , and were significantly more likely to give responses consistent with Model 2 than were subjects in the control condition,  $z = 3.9, p < .001$  (again, there was no difference in the number of subjects who fit neither of these models,  $z < 1$ ). There were again no differences between the control condition and the elementary sorting condition in terms of model use by subjects, all  $z$ s  $< 1$ . Subjects in the relational sort condition were also more likely to follow Model 2 than those in the elementary sorting condition,  $z = 3.2, p < .01$ , and were less likely to follow Model 1,  $z = 3.9, p < .001$ . The results of this analysis thus indicate that more subjects in the relational sorting condition conformed to Model 2, which takes into account the representation of both elements and relations, than those in the other two conditions. At the same time, fewer subjects in the relational sorting condition conformed to Model 1, which takes into account the representation of only elements and not relations, than those in the other conditions. Both analyses converge upon the fact that, as for propositional logic arguments, directing attention towards the spatial relations among objects significantly increased the degree to which these relations were encoded and represented.

Table 2: Numbers of subjects in each sorting condition conforming to each model type in the object arrangement task.

Sorting Condition	Processing Model		
	Model 1	Model 2	Other
Relational	9	15	11
Element	22	4	9
Control	23	4	8

## **Conclusion**

The experiment presented in this paper indicates that a knowledge-independent attentional manipulation towards relational features of information can significantly increase subsequent representation of these relations. Across two different domains, propositional logic and object arrangements, merely pointing out a relational feature in a problem and having participants sort problems by this relation led to increases in the likelihood of encoding relations and using them as recognition cues in the categorical recognition task.

These findings provide evidence that attention plays a unique role in the processing and representation of relational features of information. Further, the present study indicates that the processing and representation of relations might be at least partially due to knowledge-independent cognitive mechanisms of feature extraction.

However, while the current study supports the unique role of attention in feature processing, the manner in which attention and knowledge interact in the processing of elements and relations is still undetermined. In this study, the effects of knowledge were experimentally reduced by using simple relations in knowledge-lean and knowledge-independent domains, and by giving no accompanying explanation or definition of the relations in question. Obviously, complex relations within knowledge-rich domains require more than attention to be processed: merely giving an example of a physics problem to a novice in physics and telling them to attend to the Law of Force would be unlikely to lead to representation of this principle. Future studies should thus examine how knowledge and attention interact in determining the likelihood and manner in which relations are processed and represented.

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