Automatic processing of elements interferes with processing of relations

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Abstract

This research examines mechanisms underlying the primacy in processing of elements over relations. It is hypothesized that elements are detected atomatically even when the task is to ignore them, and this automatic detection may interfere with the processing of relations. In Experiment 1, 4 year-olds and adults were asked to ignore elemental features and to match a test item to a target by detecting the numerical equivalence beween the test and the target. Results indicate that only children, but not adults, cannot ignore elements, thus suggesting that elements could be processed automatically. In Experiment 2, the same task was presented again, except that elements were perceptually-rich. This time, both children and adults exhibited difficulty ignoring elements. These findings point to two important regularities. First, attention is automatically attracted to elements, interfering with processing of relations, and this interference may make relational processing more difficult. And second, perceptual richness of elements amplifies this effect.

Introduction

Humans live in a structured environment: we encounter entities that are interconnected spatially, temporally, or conceptually into larger arrangements. Those components of structure that are entities or separable properties of these entities can be considered elements, whereas the manner in which elements are arranged can be considered relations.

However, it is not self-evident as to what constitutes an element or a relation. For example, a letter may constitute a relational entity in a letter recognition task, but it constitutes an element in a lexical decision task. Similarly, a word may constitute a relational entity in lexical decision, but (as demonstrated by Ratcliff and McKoon, 1989) it constitutes an element in a sentence comprehension task.). Because there is evidence that stimulus familiarity is established early in the course of processing and familiar stimuli are processed by dedicated circuits (Hölscher, Rolls, & Xiang, 2003; Xiang & Brown, 1998), it seems that familiar objects are good candidates for being considered elements.

Processing of structure requires processing of both elements and relations because both elements and relations carry important information: changing a relation (e.g., *the ball is under the table* instead of *the ball is on the table*) as well as changing an element (e.g., *the book is under the table* instead of *the ball is under the table*) can radically change the nature of the information. Processing of structure and the ability to recognize the processed structure at a later time is critically important for both cognition and learning.

There is multiple evidence that pointing to a primacy of processing of elements over relations in terms of processing time, as well as phylogenetic, ontogenetic, and microgenetic time. First, researchers have found that, across a broad array of tasks, elements are processed prior to (or faster than) relations (Goldstone & Medin, 1994; Ratcliff & McKoon, 1989). Second, there is evidence that processing of some relations (e.g., numeric equivalence) is available to great primates, but even for great primates this processing requires much more substantial training than processing of elements (Thompson, Oden, & Boysen, 1997). Third, there are developmental differences in processing of elements and relations, with younger children being less likely to process relations than older children and with greater age differences in the processing of relations than elements (Gentner & Toupin, 1986; Kotovsky & Gentner, 1996). Finally, there is also a large body of evidence indicating that in knowledge rich domains, novices are more likely to process elements (i.e., individual pieces of a chess position, or entities in a problem description) more ably then relations (i.e., the arrangements of pieces in the position, or equations that underlie the solution to the problem), although experts often process relations as well as elements (Chase & Simon, 1973; Chi, Feltovich, & Glaser, 1981; Larkin, 1983; Reed, Ackinclose, & Voss, 1990; Reingold, Charness, Schultetus, & Stampe, 2001).

Taken together, these findings suggest that elements and relations are psychologically distinct. We further contend that there might be an attentional mechanism underlying the differential processing of elements and relations: elements may be detected automatically, and this automatic detection may interfere with processing of relations.

The idea of such a mechanism has been supported by several sets of findings. First, it has been found that the likelihood of processing of relations often varies with the salience of elements. For example, when Structures 1 and 2 (e.g., two sequence of triangles monotonically increasing in size) differ in elemental and relational correspondences (i.e., the leftmost triangle in Structure 1 has the same size as the rightmost triangle in Structure 2 in terms of an elemental match, whereas it corresponds to the leftmost triangle in Structure 2 in terms of its position), participants focused on relational matches when objects were perceptually impoverished. At the same time, they were more likely to focus on the elemental matches when objects were perceptually elaborated (see Gentner & Medina, 1998 for a review). Second, introduction of a simple warm-up task, which attracts attention to either to relations or to elements, markedly increases processing of relations, but not elements in a target task (Sloutsky & Yarlas, under review), thus indicating that processing of elements is at ceiling. Both sets of findings suggest that elements may be processed in an automatic and obligatory manner.

If this is the case, then elements should be detected even when the task is to ignore them, and these automatically detected elements may interfere with processing of relations. Furthermore, because young children may have difficulty deliberately directing their attention to some properties of stimuli, while ignoring others, it seems likely that children would exhibit these effects under a wider range of conditions than adults.

To test these hypotheses, we created a task, in which participants were asked to focus on a simple relation of numeric equivalence. We selected this relation because previous research demonstrated that even primates could match items having equivalent number of elements, regardless of what these elements were (Thompson, et al., 1997). We deemed it reasonable, therefore, that the relation of numeric equivalence should be available to 4-to-5 year-olds. The task (a variant of Garner's interference task) was presented as a "matching game," in which participants were presented with a Target having a particular number of identical elements (e.g., two identical shapes), and a Test item. If the Test item had the same number of elements, participants should identify it as a match, otherwise they should identify an item as a mismatch. The items were presented under three conditions. First, there was a "fixed" condition, in which the Target and Test items had identical elements, and matching or mismatching relation was the only source of variance. Second, there was a "correlated" condition, in which elements and relations varied together: a relational match accompanied an elemental match, and a relational mismatch accompanied an elemental mismatch. Finally, there was an "orthogonal" condition, in which relations and elements varied independently. Examples of items across the three conditions are presented in Figure 1.

If elements are not attended to in the course of relational processing, there would be no difference in speed and accuracy of matching across the three conditions. If, however, elements are processed automatically, there should be a difference in speed or accuracy between the orthogonal condition and the correlated conditions. Such a decrease would be a strong evidence for automatic processing of elements and fro interference of automatically detected elements in processing of relations. As mentioned above, we expect that even young children process elements automatically, and, therefore, we expect that even young participants would exhibit these effects.

Experiment 1

Method

The goal of this Experiment was to test the hypothesis that even early in development, elements are processed automatically, and this automatic processing of elements may interfere with processing of relations.

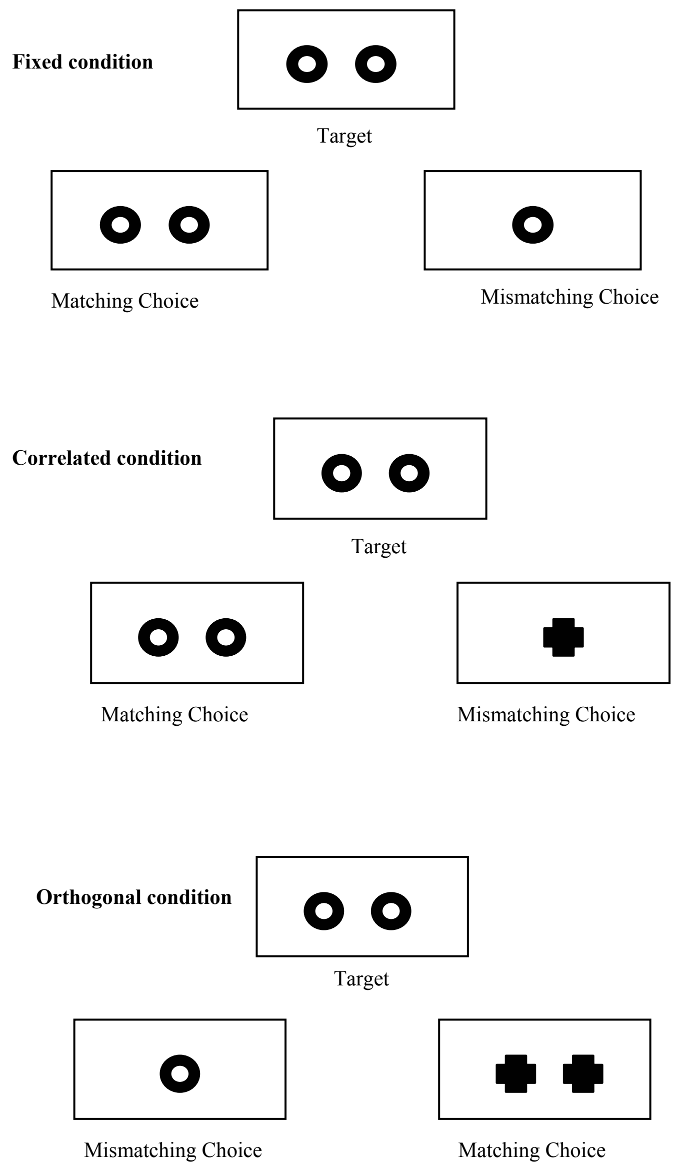

Figure 1: Example of stimuli across the three conditions.

Participants

Participants were 44 young children (Mean Age = 4.41 years, *SD* = 0.346 years; 24 girls and 20 boys) recruited from childcare centers located in middle class suburbs of the Columbus, Ohio area, with approximately equal numbers of participants in the fixed, correlated and orthogonal conditions. There was another group of 37 college undergraduates (13 women and 24 men) participating in the experiment for course credit. There was also approximately equal numbers of participants in the fixed, correlated and orthogonal conditions.

Materials

Materials were stimuli sets, each consisting of three panels. Two of these panels were Target and Choice items and these depicted simple geometric shapes (e.g., circle, triangle, cross). The third panel depicted a Trash can. Stimuli set were presented on screen with the Target and Trash can above each Choice item, with the latter one placed equidistantly to the former two. Participants were told there that if the Choice item has exactly the same number of shapes as the Target, there is a match, and they should point to the Target, whereas if the number is different, there is a mismatch, and they should point to the Trash can. There were a total of 24 trials with 12 matching and 12 mismatching trials. As mentioned above, there were three between-subjects conditions: fixed, correlated, and orthogonal.

There were exactly the same elements employed across trials in these conditions. However, within the trials, there were identical elements in all three panels in the fixed condition, elements covaried with the relation of equivalence in the correlated condition, and elements and the relation of equivalence varied independently in the orthogonal condition.

Design and Procedure

The design included two between subject factors, Condition (fixed, correlated, and orthogonal) and Age (young children and adults). Participants were randomly assigned either fixed, correlated, or orthogonal condition. The dependent variables were accuracy and latency of responses. Young children were given brief training, in which real three-dimensional objects were used to explain the rules of the "matching game." The training was identical across the three conditions.

The child participants were tested individually by a female researcher in a quiet room in their schools, whereas adult participants were tested in a lab room on campus. First, the child participants were trained on a real-object version of the computer task (this training was not used with adult participants). The researcher showed the participants two clear plastic shoeboxes. The instructions said: *This is a toy box* (pointed to box with two stars on the front) *and this is a trash can* (pointed to plain box). *There are two stars on this toy box, so this is the "two-toy" toy box. If I give you two toys, you put them in here. If I don't give you two toys, you put them in the trash can*. Then the researcher set one, two, or three toys in front of the participants and asked, "Should these go in the toy box or the trash can?" The toys were small, colorful, plastic toys (i.e. sunglasses, cars, tops). The participant was given feedback for these training trials. The participant had four trials with the two-toy toy box, after which the researcher replaced it with a one- or three-toy toy box (designated by stars on the front) and restated the instructions. Each participant had four trials with each toy box, totaling 12 training trials. If the participants were successful on the last three trials, they proceeded to the computer task. If a participant was not successful, the experiment was terminated because the participant did not demonstrate understanding of the task.

The computer task was the same as the training, except that the child participants responded by pointing to the Target or Trash can or naming them. Children's responses were entered by the experimenter. Adult participants entered their choices by pressing appropriate buttons on the keyboard. The experiment was administered on computer and was controlled by SuperLab Pro 2.0 software.

The screen was divided by a horizontal line, with the Target and Trash can above the line and the "toys" to be moved below. The toys were actually two-dimensional shapes (square, triangle, cross, circle, heart, and diamond). The researcher said to the child participants: *Now we are going to do the same thing, but on the computer. Here is the toy box (i.e., the Target) and here is the Trash can and here are the toys* (pointed to each as they were mentioned). *If the number of toys on the toy box is the same as the number of toys down here, then you tell me to put them in the box. If the number of toys on the toy box is different than the number of toys down here, then you tell me to put them in the trash.* The researcher then pressed "1" for box and "0" for trash, according to the participants' responses. The adults had similar instructions on the computer screen and two examples (one match and one mismatch). There were four warm-up trials on the computer and 24 test trials. Warm-up trials were exactly as the test trials, except that the former were accompanied by feedback.

Results and Discussion

Because procedures for children and adults differed slightly, we present their data separately. Recall that children's responses were entered by the researcher, which added time to their latencies. To adjust for this added time, we conducted a separate experiment, in which we used measured the speed of pressing buttons by the researcher. We then averaged this time across trials, and subtracted it from each child participant response.

Children. Overall child participants exhibited high accuracy of responding with 91% correct in the fixed condition, 97% correct responses in the correlated condition, and 88% correct in the orthogonal condition. There was an approaching significance difference in accuracy between the orthogonal and the correlated condition, with greater accuracy in the correlated condition, t (27) = 1.81, p = .08. Latencies across the three conditions are presented in Figure 2.

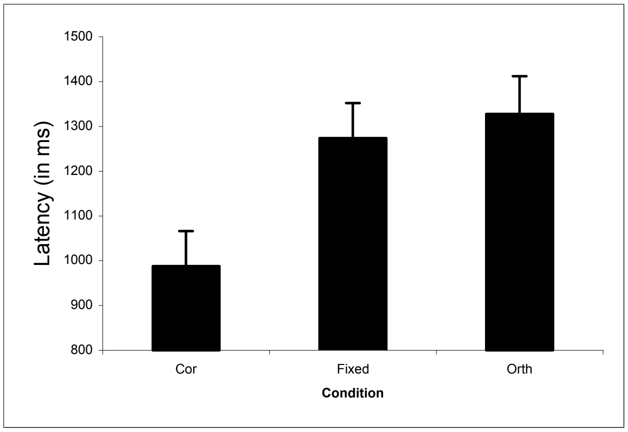

Figure 2. Children's latencies by condition. Error bars represent Standard Errors of the Mean.

These latencies were subjected to a one-way ANOVA. The analysis pointed to significant differences across the three conditions, F (2, 41) = 5, 21, p = .01. Post-hoc Tukey tests indicated that responses in the fixed and the orthogonal condition were slower than responses in the correlated condition, ps < .05. These results indicate that there was a significant speed up in the correlated condition, pointing to an automatic processing of elements.

Adults. Adults' data differed from those of young children in that there was little evidence of elements interfering with processing of relations. Adults exhibited comparable accuracy across the conditions, with 97% correct in the fixed condition, 97% correct in the correlated condition, and 95% correct in the orthogonal condition, ns, p > .3. Similarly, they exhibited comparable latencies across the conditions, 1017 ms in the fixed condition, 987 ms in the correlated condition, and 988 ms in the orthogonal condition, ns, p > .8.

Results of this experiment indicate that children, but not adults exhibit automatically processing of elements even when instructed to focus on relations.

Experiment 2

The goal of this experiment was to test the second hypothesis that perceptual richness of elements may amplfy the effects of automatic detection of elements found in Experiment 1.

Participants

Participants were 40 young children (Mean Age = 4.49 years, SD = 0.33 years; 24 girls and 16 boys). They were recruited in the same manner as in Experiment 1 and there were approximately equal numbers of participants in the fixed, correlated and orthogonal conditions. There were also 70 college undergraduates (17 women and 53 men) participating in the experiment for course credit. There was also approximately equal numbers of participants in the fixed, correlated and orthogonal conditions.

Materials

The task was set up identically to the task in Experiment 1 expect for the nature of the stimuli. Instead of the simple geometric shapes, the stimuli were perceptually rich images of common animals (e.g., bird, dog, turtle). An example of stimuli is presented in Figure 3. Again, participants were told there that if the Choice item has exactly the same number of shapes as the Target, there is a match, and they should point to the Target, whereas if the number is different, there is a mismatch, and they should point to the Trash can. There were a total of 24 trials with 12 matching and 12 mismatching trials. Again, there were three between-subjects conditions: fixed, correlated, and orthogonal.

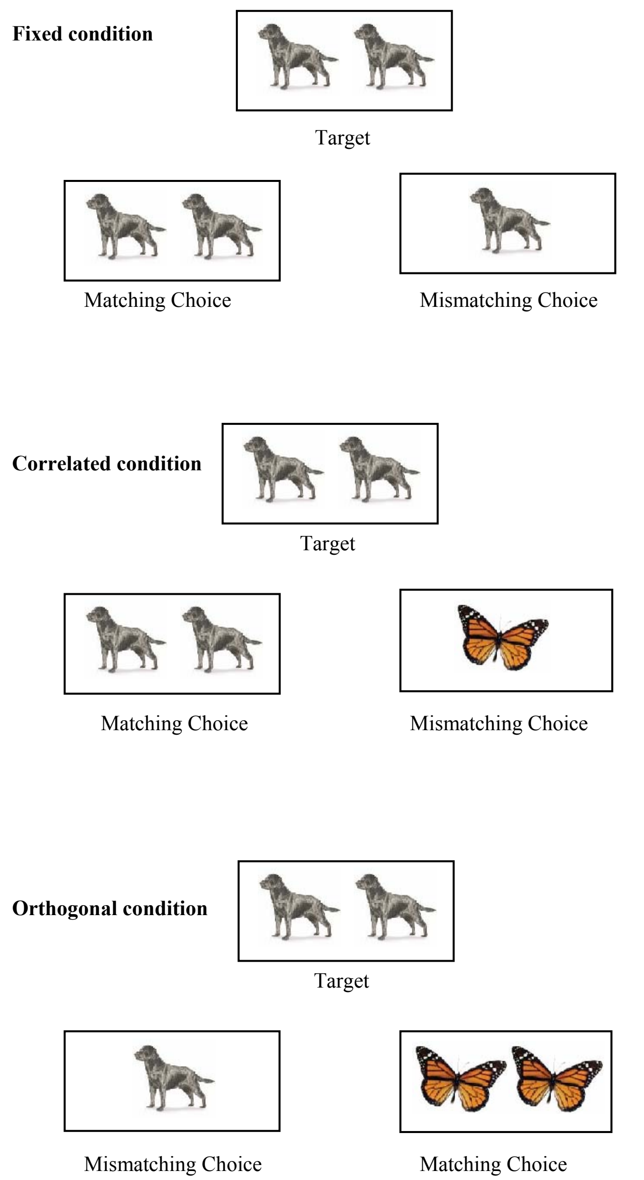

Figure 3: Example of perceptually rich stimuli across the three conditions.

Design and Procedure

The design of this experiment is identical to the design of Experiment 1. The design included two between subject factors, Condition (fixed, correlated, and orthogonal) and Age (young children and adults). Participants were randomly assigned to each level of the Condition. The dependent variables were accuracy and latency of responses. Again, young children were given brief training, identical to the training in Experiment 1 and using the same three-dimensional objects.

Results and Discussion

Data was entered and analyzed in the same manner as in Experiment 1.

Children. Similar to Experiment 1, the child participants exhibited high accuracy of responding with 94% correct in the fixed condition, 97% correct responses in the correlated condition, and 94% correct in the orthogonal condition. There were no significant differences between the accuracies of the three conditions. Latencies across the three conditions are presented in Figure 4.

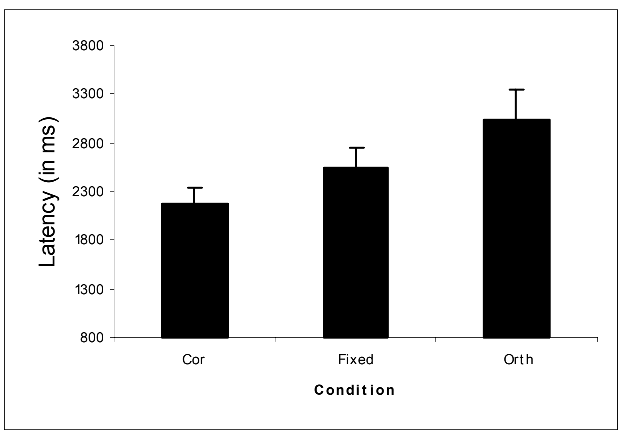

Figure 4. Perceptually rich stimuli. Children's latencies by condition. Error bars represent Standard Errors of the Mean.

These latencies were subjected to a one-way ANOVA. The analysis pointed to significant differences across the three conditions, F (2, 36) = 3.60, p = .038. Post-hoc Tukey tests indicated that responses in the orthogonal condition were slower than responses in the correlational condition, p = .03. These results indicate that there was a significant slow down in the orthogonal condition, pointing to an interference on the part of perceptually rich elements.

Adults. Adults exhibited interference effects showing somewhat lower accuracy in the orthogonal condition with 97% correct in the fixed condition, 97% correct in the correlated condition, and 92% correct in the orthogonal condition. The one-way ANOVA pointed to significant differences across the three conditions, F (2, 67) = 3.41, p = .04. Post-hoc Tukey tests indicated a significant difference in accuracy between the orthogonal and the correlated condition, with greater accuracy in the correlated condition, p = .05, and an approaching significance difference in accuracy between the orthogonal and the fixed condition, with greater accuracy in the fixed condition, p = .08. They exhibited comparable latencies to the children across the conditions, 911 ms in the fixed condition, 943 ms in the correlated condition, and 1017 ms in the orthogonal condition, ns, $p > .8$.

Results of this experiment indicate that increasing the perceptual richness of the elements produces more interference of automatically detected elements with processing of relations not only in children, but also in adults.

General Discussion

Two important findings stem from the reported experiments. First, when elements are perceptually impoverished, and the task is to focus on relations, young children automatically attend to elements. And second, perceptual richness of elements amplifies this effect in children, and it reveals the effect in adults.

Findings that elements are attended to automatically, even when the task is to ignore them, may explain the earlier found primacy in processing of elements. As mentioned above, elements are processed prior to (or faster than) relations (Goldstone & Medin, 1994; Ratcliff & McKoon, 1989), younger children are less likely to process relations than older children (Gentner & Toupin, 1986; Kotovsky & Gentner, 1996), and experts in a domain are more likely to process domain-important relations than novices (Chase & Simon, 1973; Chi, Feltovich, & Glaser, 1981). These findings suggest that the difficulty of processing relations may often stem from participants inability to ignore irrelevant elements.

This attentional mechanism is capable of explaining several existing findings. In particular, there is evidence (see Gentner & Medina, 1998; Markman & Gentner, 1993) that when elements are perceptually-rich, participants are more likely to focus on matching elements than when elements are perceptually-impoverished. Because perceptually-rich stimuli are more likely to engage attention than perceptually-impoverished stimuli, it seems that differences reported by Gentner & Medina (1998) may stem from greater attention automatically attracted to perceptually-rich elements.

Finally, there is evidence that although young children have difficulty processing relations under regular conditions, they are significantly more likely to process relations when relations are labeled (Gentner &

Loewenstein, 2002; Kotovsky & Gentner, 1996). Again, it seem that labels attract attention to relations thus making it easier to ignore elements.

It seems that these examples demonstrate that, unless attention is attracted to relations and away from elements, participants are more likely to automatically attend to elements, and attention to elements may interfere with their processing of relations. Recall that current research used a highly familiar relation of numerical equivalence, and interference effects manifested themselves in a decresed latency or accuracy. However, it is possible that when relations are less familiar, interference may result in a failure to detect a relation.

In short, reported results indicate that elements are detected automatically. The results also indicate that perceptual richness of elements amplifies the effect of automatic detections of elements. It is possible that automatic detection of elements may interfere with processing of relations, especially when the task is to ignore elements.

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