Theories and Similarity: Categorization under Speeded Conditions

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Abstract

A largely accepted view in the categorization literature is that similarity-based reasoning is faster than theory-based reasoning. In the current study, we explored whether theory-based categorization behavior would continue to be observed when people are forced to make category decisions under time pressure. As a specific test of the theory-based view to category representation we examined the causal status hypothesis, which states that properties acting as causes are more important than properties acting as effects when categorizing an item. Subjects learned four categories of items composed of three features and learned causal relations between those features. In two experiments we found that participants gave more weight to cause features than to effect features even under rapid response conditions. We discuss implications of these findings for categorization.

Introduction

When posed with categorization tasks in everyday life people recruit information from a variety of sources. In general, previous work on categorization has focused on two sources of information: similarity and theories. One family of categorization theories has centered on the notion of similarity (e.g., Kruschke, 1992; Nosofsky, 1986; Smith & Medin, 1981; Rosch & Mervis, 1975). On this view concept learning and use is based on computing the similarity between an object to be categorized and a stored representation of a category (e.g., exemplars, Nosofsky, 1986; or prototypes, Hampton, 1995).

An alternative view assumes that people have theories that embody relations between properties and influence categorization behavior (Carey, 1985; Keil, 1989; Murphy & Medin, 1985; Rips, 1989). An illustrative example comes from Keil's (1989) discovery experiment. When presented with an animal that had the appearance and behavior of a horse but the insides and lineage of a cow, adults would categorize the animal as a cow. This behavior suggests that lineage has a special status above and beyond perceptual features, presumably reflecting the importance of lineage in our lay theory of biology. Similarly, Medin and Shoben (1988) showed that people would rather accept a square cantaloupe than a square basketball, presumably because "being round" is more central in naïve theories of physics (i.e., the domain in which basketballs are grounded) than in naïve theories of biology (i.e., the domain in which cantaloupes are grounded).

The similarity-based and theory-based views are not necessarily incompatible (e.g., Sloman & Rips, 1998). In fact, many proponents of either view allow for, or even advocate, the operation of both kinds of processes (e.g. Sloman, 1996; Smith & Sloman, 1994). However, these proposals typically put the two views on unequal footing. A persistent bias present in these 'hybrid' models is that similarity-based categorization is primary. For instance, in the developmental literature, it has been argued that theory-based mechanisms cannot precede similarity-based mechanisms in development because theories must be acquired through similarity-based mechanisms (Quine, 1977; Vygotsky, 1962; but see Keil, Smith, Simons, & Levin, 1998). Thus, only after sufficient experience has been obtained may theories be developed and used, amending (or supplanting) similarity-based information.

In addition to the idea that similarity-based categorization is developmentally primary, there is a notion that similarity-based information is accessed more rapidly, and perhaps more automatically, than theory-based information. This assumption may be motivated by the observation that novices (e.g., children) use similarity-based reasoning and thus it is a somehow simpler mode of reasoning (cf. Keil et al, 1998). Smith and Sloman (1994) make this argument explicit by assuming that theory-based reasoning is a type of rule-based reasoning, arguing that rule-based reasoning is, "more analytic and reflective than similarity-based categorization" (pp. 377-378).

To test this assumption Smith and Sloman designed a study to examine the effect of time constraints on theory-based (or rule-based) categorization. Smith and Sloman's subjects performed a forced-choice task in which each item consisted of a description of an object paired with two possible categories (task and stimuli adapted from Rips, 1989). Each item had one response that corresponded to a rule-based (i.e. theory-based) decision and one that corresponded to a similarity-based decision. For example, "Circular object with a 4 inch diameter" could be categorized as a pizza or a quarter. Calling this object a pizza would signify theory-based understanding of the minting process whereas calling this object a quarter would signify a similarity computation because a circular 4-inch object is more similar to quarters that to most pizzas (but see Nosofsky & Johansen, 2000). Rips (1989) found that people tended to choose the theory-based response. However, when asked to respond as quickly as possible, subjects in Smith and Sloman's study failed to reproduce this result. Only when instructed to talk aloud while categorizing did subjects tend to answer in accordance with the theory-derived rules. Thus, Smith and Sloman concluded that a "…possible constraint…is that the situation encourage people to articulate and explain their reasons for categorization, rather than encourage rapid judgments" (p. 383).

One problem with this interpretation is that the use of either similarity or theories resulted the in subjects accepting bizarre objects as category members. For instance, participants had to decide whether a circular object with a 4-inch diameter that is silver colored is a pizza or a quarter. This is a rather strict test of theory-use and may not represent a naturalistic situation in which to test the influence of speed.

More recent studies have suggested that theory-based categorization may be at least as fast as (and perhaps as automatic as) similarity-based categorization. For example, Lin and Murphy (1997) pitted perceptual similarity against knowledge of an object's function during speeded categorization. For instance, an object with a loop was either described as a tool used to hunt animals where the loop is placed around the animal's neck, or a pesticide sprayer where the loop was used to hang it when not in use. Thus, the loop should have been viewed as central to the category in the former condition and more peripheral in the latter condition. Even when category responses had to be made within a one-second deadline, or when the picture of the object to be categorized was presented for only 50ms and then masked, subjects continued to be influenced by domain knowledge (e.g., the object's described function).

Palmeri and Blalock (2000) reported a similar pattern of results. Extending the findings of Wisnewski and Medin (1994), they had subjects categorize drawings supposedly drawn by children described as either "creative" or "non-creative." Subjects were able to categorize using this background knowledge (e.g., by the amount of emotional expression) even when the pictures were shown for only 200ms. Their study demonstrated that theory-use did not require lengthy periods of reflection.

The main goal of the current study was to build upon these recent findings and to examine speeded theory-based categorization at a finer level. As a specific test of the theory-based view we have chosen to examine the causal status hypothesis (CSH; Ahn, Kim, Lassaline, & Dennis, 2000; Ahn, 1998). This hypothesis was developed in response to the valid criticisms that specific mechanisms underlying theory-based categorization had not been explicated. CSH states that features of an object that act as causes in one's domain theory are more important than features that act as effects, ceteris paribus. This measure, referred to as *causal depth*, makes explicit why some features are more central to one's theory than others.

As a test of the CSH, Ahn et al. (2000) provided subjects with novel categories that possessed features at different causal depths. When asked to classify possible category members, each of which was missing a single characteristic feature, subjects rated those missing an effect feature as a better category member than those missing a cause feature. In the current study we employed a similar methodology to test the effects of time pressure on the causal status effect.

Experiment 1

Method

Adapting the paradigm from Ahn et al. (2000), our stimuli consisted of four fictional animals (see Fig. 1). Each animal was described as possessing three features. The features were described as having a causal chain structure such that feature A causes feature B, and feature B causes feature C.

It is crucial to ensure that, in the absence of causal information, the three features did not vary in salience. Otherwise, any obtained causal status effect could not be solely attributed to the causal background knowledge but could instead be attributed to some other factor (e.g., physiological feature versus behavioral feature). To eliminate this possibility we pre-tested the stimuli on a separate set of subjects, using the animal descriptions without the explicit causal information. Subjects were then asked to rate the likelihood of category membership of items missing a single feature (see Fig. 2). The results of this pre-test showed no significant differences between the ratings of items missing the first feature, items missing the second feature, and items missing the third feature (all p's>.4). Thus, we concluded that the features were equated for a priori strength.

In the categorization tasks used by Ahn et al. (2000), subjects were allowed to view the animal descriptions (along with the causal structure information) while they were making their category judgments. To allow for speeded responses, subjects in our study were instead required to learn and memorize the four animals, their features, and the causal relations between the features. First, subjects were given the opportunity to study the description of each animal at the beginning of the experiment. While studying each description subjects were instructed to "write about how you think each feature causes the next," in an attempt to force subjects to think causally about the features (instead of as a simple ordered list). To help subjects further learn the items, they were then presented with 6 blocks of trials, during which they were prompted with the name of one of the animals and were required to select (using a mouse-click) the features of that animal from an array containing the features of all 4 animals. They were required to select those features in the appropriate causal order. Successfully responding to the entire set of animals twice allowed subjects to move on to the next block. In the first two blocks responses were unspeeded, while in the last four blocks responses had 5-second deadlines (any response not meeting the deadline was counted as incorrect). This speeded-learning procedure was added so that the novel causal background knowledge would be sufficiently internalized, thereby approximating real-life lay theories. In addition, on half of the blocks, subjects were asked for the causal relations in the forward order (e.g. A, B, C) and on the other half in the backward order (e.g. C, B, A). The order manipulation alternated across blocks and subjects, always beginning with a forward block.

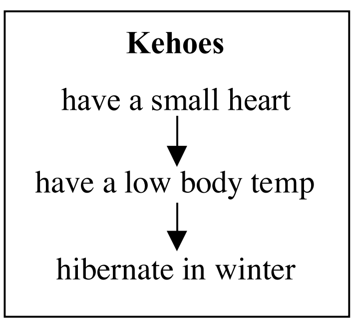

Figure 1: A sample animal with causal links

Once subjects completed these six blocks they proceeded to the experimental transfer task. Subjects were presented with items missing a single feature and were asked to rate the likelihood that the item belonged to its target category on an 8-point scale (with 1 being "Definitely Unlikely" to 8 being "Definitely Likely"). Features of each transfer item were presented in a triad as shown in Figure 2, with the position of the features randomized.

There were 4 blocks of trials in the transfer task. In two of the blocks, subjects were instructed to answer as quickly as possible. In the other two blocks, they were told to take as much time as needed. The speed condition alternated across blocks and was counterbalanced across subjects.

For the unspeeded trials we expected to find results similar to those of Ahn et al. (2000). That is, items missing the terminal effect feature should be rated as more likely category members than those missing the initial cause feature. The critical question was whether this causal status effect would disappear during the speeded trials, as suggested by Smith and Sloman (1994).

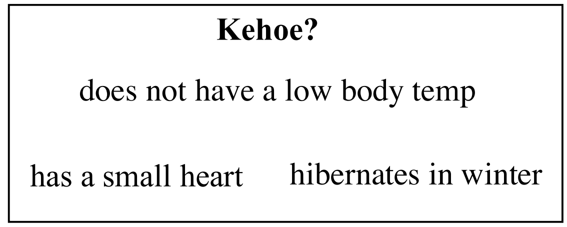

Figure 2: A sample transfer item from Experiment 1

Results and Discussion

Before analyzing the subjects' category ratings, we verified the instructional speed manipulation. The RTs in the speeded blocks (M = 1560ms) were indeed significantly faster than the RTs in the unspeeded blocks (M = 3202ms), $p<.05$, Tukey's HSD.

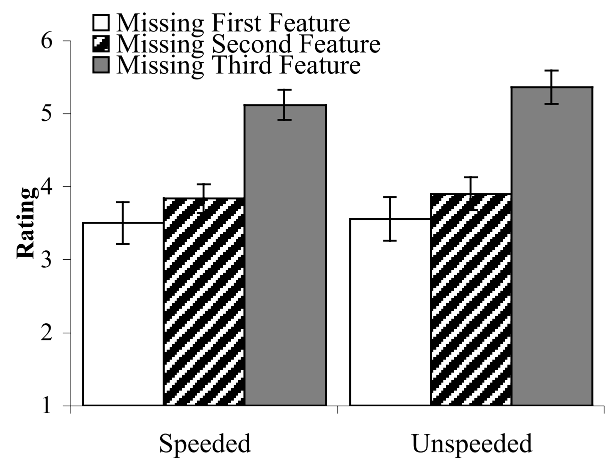

Figure 3: Results from Experiment 1

The results for subjects' categorization responses are summarized in Figure 3. A 2 (speed condition: speeded vs. unspeeded) X 3 (item type: missing first feature vs. missing second feature vs. missing third feature) repeated measures ANOVA was performed on the data. We observed a significant main effect of item type, $F(2, 56)=22.69$, $p<.0001$, demonstrating that subjects categorized in accordance with the causal status hypothesis. In addition, we observed no main effect of speed, $F(1,28)=2.89$, $p>.05$, and the speed X item type interaction was also not significant, $F(2,56)=1.03$, $p>.05$.

Planned comparisons were carried out to examine differences between item types. In both the speeded and unspeeded conditions items missing the third feature were rated significantly higher than those missing the first or second features (p's<.05, Tukey's HSD). The difference between items missing the first feature and those missing the second feature was not significant (p's>.05, Tukey's HSD), possibly because the second feature also served as a cause of another feature, making the difference between the first and the second feature less pronounced (see also Kim and Ahn, 2002).

Overall, these results demonstrate that it is possible to categorize using causal knowledge even when time for lengthy reflection is not allowed. It is tempting to contrast our findings with those of Smith and Sloman (1994). In their experiment, subjects needed unspeeded conditions and to talk aloud while making the judgment in order to demonstrate theory-based behavior. It is possible that the paradigm used by Rips (1989) and Smith and Sloman (1994) created a situation in which theory-use was more difficult to apply than our situation (see above). Nevertheless, our findings clearly question the assertion that theory-use is relegated to situations in which reflection and analytic thought is permitted.

Experiment 2

In Experiment 1, subjects were simply asked to respond as quickly as possible to the "speeded" items. Given this freedom, some subjects responded very quickly but others responded significantly more slowly. Although the speed manipulation we used in Experiment 1 is naturalistic, in that participants carried out what they thought to be a rapid decision making process, forcing participants to respond within a specific deadline would ensure uniform time pressure across all subjects. Therefore, in Experiment 2, we imposed stricter control over subjects' response times by enforcing deadlines on their category decisions.

One methodological complication with establishing appropriate response deadlines is that it is difficult to determine beforehand whether a particular deadline is short enough to challenge the categorization system but not so short as to make accurate responses impossible. That is, if the speeded condition does not show the causal status effect, it can be because theory-based reasoning does not take place during rapid categorization or because the deadline is too short to produce any reasonable responses.

For this reason, we also tested whether similarity information could be used under similar deadlines. By testing both kinds of knowledge, the casual status effects can be compared to similarity-based categorization at each deadline. In this way it can be inferred whether any breakdown of the causal status effect is due to the inability to complete the processes necessary for theory-based categorization or if reasonable responses at that deadline are impossible for both kinds of categorization.

Similarity is frequently calculated based on how many attributes an item has in common with other members of the category (e.g., Tversky, 1977). Therefore, as a similarity-based determinant for feature weighting, we manipulated the relative base rates of each feature within a category (i.e., what percentage of category members possess a feature), a measure also known as *category validity*. In fact, category validity has been shown to be positively correlated with typicality ratings (Rosch & Mervis, 1975).

Experiment 2 contains a similarity condition that provides category validity information in much the same way causal information was provided in Experiment 1. Using this condition as a point of comparison, and with the addition of strict response deadlines, we hope to provide a more rigorous test of the causal status effect under speeded conditions.

Methods

Subjects in the Causal condition were given the same stimuli and accompanying causal information as used in Experiment 1. Subjects in the Base-Rate condition were given the same stimuli but were instead given information about the relative base rates of each feature. Thus, each category was described as having three features (e.g. A, B, and C) such that 100% of category members possessed feature A, 80% of possessed feature B, and 60% possessed feature C. In our parlance, the Causal condition represents a theory-based situation whereas the Base-Rate condition represents a similarity-based situation. Paralleling the results of Experiment 1, items in the Base-Rate condition missing the third (60%) feature should be rated as better category members those missing the first (100%) feature. This is because those missing the third feature share more features with more category members than those missing the first feature.

The learning phase for the Causal condition was identical to that used in Experiment 1. Subjects in the Base-Rate condition did not have to generate explanations but instead categorized exemplars into one of the four animal categories. For this task, each exemplar always possessed the first feature of its category, possessed the second feature on 80% of the trials, and the third feature 60% of the time (thus mirroring the stated base rates). When a given feature did not appear in an exemplar, a feature from one of the other animals was substituted. Feedback was given after each trial.

Blocks of 30 such trials alternated with blocks of the "selection task" used in the Causal condition. The only difference was that features were selected in an order (forward or backwards) dictated by their base rate rather than their position in the causal chain.

The transfer phase for both conditions was nearly identical to that used in Experiment 1 except for a modified speed manipulation. Instead of an instruction to respond quickly, Experiment 2 employed a signal-to-respond technique (Lamberts, 1998). Thus, each trial presented the feature triad (Fig. 2) for a specified duration (see below). When the triad was removed from the screen subjects made their response. If a response was made more than 300ms after the disappearance of the triad, subjects were told to respond more rapidly.

There were four blocks of trials. Each block used one of four presentation durations (1500ms, 750ms, 500ms, and 300ms). These blocks were ordered randomly for each subject.

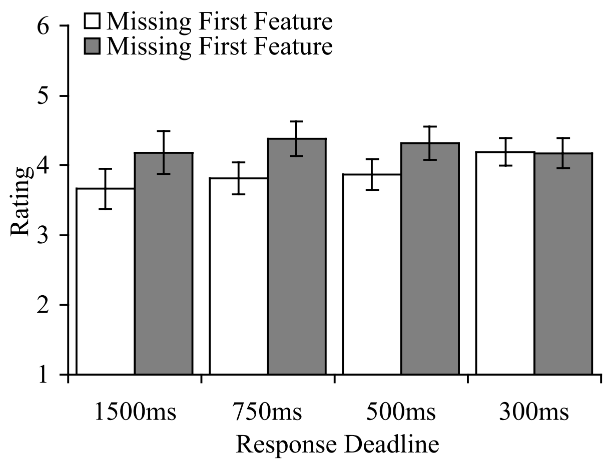

Figure 4: Results from Causal Condition

Results and Discussion

The results from the categorization task can be seen in Figures 4 and 5. A 2 (knowledge condition: Causal vs. Base-Rate) X 4 (speed condition: 1500ms vs. 750ms vs. 500ms vs. 300ms) X 2 (item type: missing first feature vs. missing third) ANOVA was performed with repeated measures on the latter two factors. We observed a significant main effect of item type, $F(1, 58)=15.14$, $p<.0005$, that did not interact with knowledge condition, $F<1$, demonstrating that both background conditions had the predicted effect on categorization behaviors. No significant main effect of speed was observed, $F(3, 174)=1.88$, $p>.05$, but this main effect must be interpreted in light of a significant interaction between speed and item type, $F(3, 174)=6.26$, $p<.001$, which will be further examined below. No significant main effect of background condition was observed, $F(1, 58)=3.43$, $p>.05$, and this factor did not interact with either of the other two factors. The three-way interaction between background condition, speed, and item type also failed to reach significance, $F(3, 174)=1.93$, $p>.05$.

Planned comparisons were carried out to determine at what response deadlines the background information had a significant effect on categorization. For simplicity, we only report comparisons between items missing the first feature and those missing the third, the differences that CSH predicts to be the largest. For the Base-Rate condition, items missing the first (100%) feature significantly differed from items missing the third (60%) feature in the 1500ms condition, $t(29)=3.43$, $p<.005$, and the 750ms condition, $t(29)=2.41$, $p<.05$, but not in the 500ms, $t(29)=.3$, $p>.05$, or 300ms, $t(29)=1.59$, $p>.05$, conditions. In the Causal condition, items missing the first (initial cause) feature differed from those missing the third (terminal effect) feature in the 1500ms, $t(29)=2.22$, $p<.05$, the 750ms, $t(29)=2.86$, $p<.01$, and the 500ms conditions, $t(29)=2.06$, $p<.05$, but not the 300ms condition, $t(29)=.81$, $p>.05$.

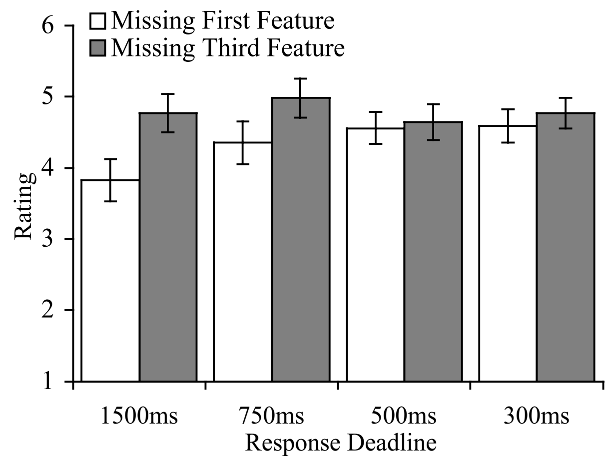

Figure 5: Results from Base-Rate condition

In light of these results, it is clear that theory-driven causal knowledge can be utilized to categorize stimuli under even faster conditions than those created in Experiment 1. Subjects in this experiment were able to categorize according to their theory even when allowed only 800ms to view the exemplar and make a response. This is impressive considering that this condition was 200ms condition faster than the speeded condition used by Lin and Murphy (1997; Experiment 4) – their stimuli were pictures whereas ours were verbal descriptions. Furthermore, our results indicate that the base rate information, which has been considered a key determinant of similarity (Rosch & Mervis, 1975), did not result in differential responses under this deadline. The results taken together provide strong evidence that theory-based categorization cannot be slower than similarity-based categorization.

Conclusion

The current experiments demonstrated two important findings: First, theory-based categorization, as measured by the causal status effect, did not necessarily require excessive periods of deliberation in order to exert an influence on behavior. Second, the latencies at which theory-use is possible are comparable to those of similarity-use. These findings bolster the idea that use of similarity is not necessarily more primary than theory-use. Instead, it appears that people's use of theories and similarity may be inexorably intertwined, not just during development (Keil, et al., 1998) but during the course of a single category decision as well.

One open question concerns the type of reasoning that takes place when subjects actually categorize transfer items. Was any causal reasoning taking place during the transfer tasks, or were subjects simply retrieving pre-compiled notions about feature importance derived during learning? Future studies on this issue will help us develop more detailed processing accounts of theory-based categorization. The current results, at the very least, clearly demonstrate that previously acquired causal knowledge influences later categorization judgments even when rapidly categorizing objects.

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