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The Roles of Causes and Effects in Categorization

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Abstract

The effect of knowledge about causal relationships between category attributes on categorization decisions was investigated. Participants were taught that category attributes were causally related in either a common-cause or a common-effect causal pattern. The weight given to attributes during subsequent categorization depended on the causal pattern: In the common-cause condition the common cause was weighted most heavily, whereas in the common-effect condition the common-effect was weighted most heavily. Participants also attended to correlations between causally related features, generating lower categorization ratings if a cause-effect relationship was violated. Participants displayed a wide variety of different strategies in making categorization decisions, including ones that employed higher-order configural information involving more than two attributes. There was no effect of the "kind" of the category (biological kind, nonliving natural kind, or artifact) on categorization decisions, and kind of category did not interact with causal pattern.

One of the focal research questions for cognitive scientists studying conceptual thinking concerns the role of background knowledge, "theoretical glue," or explanations in the mental representation of category concepts. One proposal is Ahn and Lassaline's (1996a) *causal status hypothesis* which states that category attributes that are causes carry more weight than effects during categorization. For example, because having wings causes flying, an exemplar that flies but has no wings is less likely to be considered a bird than an exemplar that has wings but doesn't fly. In a series of experiments Ahn and Lassaline (1996a, 1996b) indeed found that category membership likelihood ratings were less for exemplars missing a cause than exemplars missing an effect.

Similarly, Sloman, Love, and Ahn (1996) have proposed that features that are *depended on* are less mutable than those that are not. Cause-effect relations are one example of such dependency relations where the effect depends on the cause, making the cause less mutable. Immutable features such as causes are predicted to be more important for categorization than mutable features. Sloman, et al., found that category typicality ratings were lower for exemplars missing immutable features than for exemplars missing mutable features.

The present study attempts to (a) extend these important findings to a wider range of causal patterns, (b) determine the interaction between causal pattern and the ontological kind of the category, and (c) investigate the impact of mismatches between causes and effects on categorization. Concerning causal patterns, we test whether the greater importance of causes over effects extends to those shown in Figure 1, the *common-cause* pattern in which a single attribute (A1) causes the remaining attributes (A2, A3, and A4), and the *common-effect* pattern, in which a single attribute (A4) is caused by A1, A2, and A3.

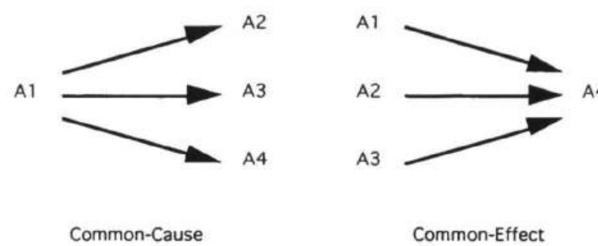

Figure 1

The common-cause and common-effect causal patterns are theoretically interesting for a number of reasons. First, Medin and Ortony (1989) have proposed that people believe that things in the world have *essences*, (even if they don't know what the essence is; and even if the categories do not truly have essences), a view they call *psychological essentialism.* If psychological essentialism is correct, then people are tuned to learn categories that include an underlying essence that is causally responsible for other features. Thus, a belief in a causally-potent internal essence may be identified with a specific pattern of causal links, namely, the common-cause pattern in Figure 1. An exemplar missing a common-cause may be especially unlikely to be considered a category member as compared to an exemplar missing a non-common cause.

Second, the common-cause and common-effect patterns allow us to compare the causal status hypothesis with an alternative hypothesis, namely, structure-mapping theory (Gentner, 1989). Gentner suggests that feature importance is determined by the number of relations in which the attribute participates. In the common-effect causal pattern the common-effect participates in three relationships whereas the other attributes participate in only one. Thus, the causal-status hypothesis predicts that the causes in the common-effect pattern should be more important, but structure-mapping theory suggests the opposite.

Third, abstract causal patterns like those in Figure 1 have been studied by Waldmann, Holyoak, and Fratianne

(1995). They found that a *varying-cause* common-cause pattern (one in which the causal feature takes on different values) was most consistent with learning non-linearly separable category structures because of the presence of correlations between features, but a *constant-cause* common-cause pattern and the common-effect pattern were most consistent with learning linearly separable category structures. Waldmann, et al. were able to induce in subjects different causal models by providing information about causal directionality, and the continuity and variability of causal factors. It is important to extend the causal-status hypothesis to these causal patterns if indeed they serve as domain-general causal schemas as Waldmann, et al. suggest.

The consequences of common-cause and common-effect patterns may depend on the kind of category to which they are attributed. For example, the philosophical analysis of categories (Putnam, 1975; Schwartz, 1977) has suggested that there may be important differences between natural kinds and artifacts: People may believe in essences for natural kinds more than they do for artifacts (Keil, 1989). However, it may be more accurate to say that the essence of artifacts is different than the essence of natural kinds. For example, Rips (1989) found that missing "essential" properties affected categorization more than missing "accidental" properties for both natural kinds and artifacts, but the essence for natural kinds was an intrinsic property (e.g., developmental history, parentage) while the essence for an artifact was its function (see Malt, 1992, 1994 for a contrary view on the generality of essences).

The present experiment also investigates whether cause-effect relations between category attributes have effects on categorization beyond the weight given to individual features. Whether a cause and effect are consistent with each other (i.e., if the cause is absent the effect is absent, and if the cause is present the effect is present) may also have a large effect on whether an exemplar is considered a category member. Detecting matches between cause and effect attributes is equivalent to detecting whether an expected correlation is violated, which may be considered a higher-order configural property like those assumed by certain feature-frequency models of categorization (Gluck & Bower, 1988; Hayes-Roth & Hayes-Roth, 1977; Reitman & Bower, 1973). Indeed, there is evidence that people detect and use information about violated correlations during categorization as long as those correlations are expected based on prior knowledge (Malt & Smith, 1984; Murphy & Wisniewski, 1989). Because our experimental participants were taught about causal relationships between category attributes in the experimental setting, these relationships should be salient, and thus may play a role in categorization decisions.

In summary, the current experiment investigates the effect of causal pattern (Figure 1) and kind of category on categorization decisions. As we shall show, while causal pattern had a large effect on categorization performance, the kind of category did not, and these factors did not interact. In addition, we shall demonstrate that categorization depends in part on whether cause and effect attributes are consistent with one another, and that there are large differences in how individuals utilize causal information in making categorization decisions.

Method

Materials

Our aim was to create materials that described categories of objects that could really exist. We constructed materials for six categories: Two biological kinds (Kehoe Ants and Lake Victoria Shrimp), two nonliving natural kinds (Myastars and Meteoric Sodium Carbonate), and two artifacts (Romanian Rogos and Neptune Personal Computers). Each category possessed four binary attributes, the values of which were either abnormal or normal relative to its superordinate category. For example, the attributes and attribute values for Kehoe Ants are given in Table 1.

Attribute	Attribute Description	Abnormal Value	Normal Value
A1	Iron sulfate in blood	High	Normal
A2	Immune system	Hyperactive	Normal
A3	Consistency of blood	Thick	Normal
A4	Nest building	Fast	Normal

Table 1

With four attributes per category, there were five causal links that needed to be developed in order to construct the common-cause and common-effect patterns of Figure 1: A1→A2, A1→A3, A1→A4, A2→A4, A3→A4. Each causal link was described as the abnormal value of one attribute causing the abnormal value of another attribute. Ideally, one would want to counterbalance the assignment of cause and effect roles to attributes. However, we found it was impossible to counterbalance causal links over attributes and still have the causal explanations between attributes be plausible. In order to assure that our results are general beyond the particular categories and attributes we used, we performed extensive pretesting of the plausibility of causal relationships to produce causal links of equal plausibility across causal patterns and categories. Pretest subjects received questionnaires in which they rated the plausibility of each causal link for each category, and also a "reversed" version of each link in the which the cause had the opposite influence on the effect. We assumed that equal ratings for a link and its reverse link meant that a subject had no prior knowledge about the cause/effect relationship between the two attributes. There were two cycles of pretesting: The initial causal links were tested, and problem links (those that had low plausibility ratings, or ratings that differed from those of their reverse link) were identified and rewritten. The materials were then retested, and found satisfactory. A description of five causal links for one category, Kehoe Ants, is presented in the Appendix.

Participants

81 University of Colorado undergraduates attending an introductory psychology class received course credit for participating in this experiment.

Design

Subjects were randomly assigned to one of the six categories, and to either the common-cause or common-effect condition.

Procedure

All phases of training and testing were presented by computer. In the first learning phase subjects received conceptual information about the category. They studied five screens of information about the category, including cover story, attributes, attribute values and their base rates (each attribute was described as having an abnormal value 75% of the time and a normal value 25% of the time), a verbal description of the causal relationships, and a diagram summarizing the causal relationships. Subjects studied this information at their own pace, and were able to move back and forth through the five screens. When ready, subjects took a 21-item multiple-choice test that questioned them about (a) which values an attribute could take, (b) what the causes of an attribute were, (c) what the effects of an attribute were, and so on. If unable to answer a question, subjects could request "help" which would cause the computer to re-present the five screens of information. Subjects were required to retake the test until they committed 0 errors and made 0 requests for help.

In the second learning phase, subjects received statistical information about the category in the form of category exemplars. Subjects were told that they would see 64 exemplars, 32 of which were from the target category (e.g., "Kehoe Ants") and 32 from an "other" category (e.g., "some other kind of ant"), and would classify each. Target category exemplars were generated with attribute base rates that matched the verbal description of the category (75% abnormal, 25% normal). However there were *no* correlations between attributes. That is, the correlations that would be implied by the common-cause or common-effect causal pattern they just learned the category possessed were *not* reflected in the category exemplars. (As a result of holding statistical information constant across conditions, any effects of causal pattern we observe must be attributable to differences in conceptual knowledge that subjects learn.) The attributes of the 32 exemplars from the "other" category had normal values 75% and abnormal values 25% of the time, and again there no correlations between attributes. Subjects received feedback with each categorization trial.

Subjects then performed a transfer categorization test. For 32 exemplars they gave their confidence that the exemplar was a member of the target category. The 32 exemplars consisted of all possible 16 examples that could be formed from four binary attributes, each presented twice. During this phase subjects received no feedback.

Results

We report results of the transfer categorization test. Our interest was in determining how important each feature was in making a categorization decision, and how important it was that an exemplar did not violate the correlations implied by the category's causal links. We coded each variable a_i as -1 if it had a normal value on attribute i, and as +1 if it had an abnormal value, and then performed a multiple regression for each subject in which a subject's confidence judgments was regressed onto 15 predictors consisting of the a_i's (a_1, a_2, a_3, a_4), the six two-way interactions (a_1a_2, a_1a_3, etc.), the four three-way interactions ($a_1a_2a_3$, etc.), and the single four-way interaction. The two-way interaction terms code whether the subject utilizes correlations between attributes. The regression weights averaged over subjects for each a_i are presented in Figure 2.

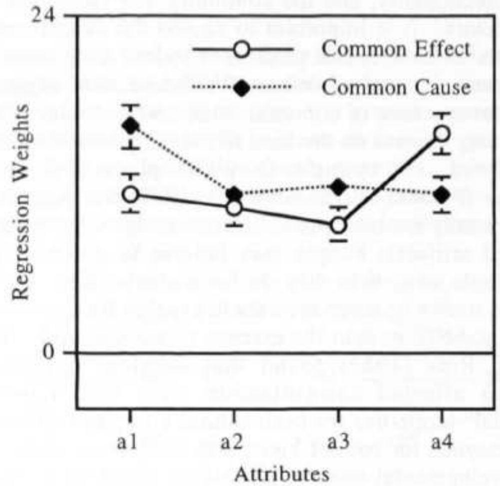

Figure 2

Figure 2 demonstrates a clear effect of causal pattern on weights given to attributes in producing category-membership confidence judgments. In the common-cause condition, subjects weighted the common-cause attribute, a_1, more heavily than the effect attributes. In the common-effect condition, however, the common-effect attribute, a_4, was weighted most heavily. These results obtained despite the fact that in both conditions subjects were given explicit verbal information that the base rates of all features were identical, and that the base rates of features were identical in the 32 target-category exemplars they classified. These conclusions are supported by statistical analysis. A 2x6x4 analysis of variance with causal pattern and category (Kehoe Ants, Romanian Rogos, etc.) as between-subject factors, and attribute regression weight (a_1, a_2, a_3, a_4) as a within-subject factor was performed. The only significant effect was an interaction between attribute weight and causal pattern ($F(3, 207)=5.79$, $p<.005$), indicating that the weights given to attributes were different in the common-cause and common-effect conditions. A separate analysis of the common-cause condition revealed that the weight of the common-cause was significantly greater than the mean weight of all other attributes ($F(1, 38)=6.40$, $p<.05$). Likewise, in the common-effect condition the weight of the common-effect was significantly greater than the mean weight of all other attributes $F(1, 41)=9.52$, $p<.01$. Finally, the weight given to A1 was greater in the common-cause than in the common-effect condition ($F(1,69)=4.97$), $p<.05$), and the weight given to the A4 was greater in the common-effect condition than in the common-cause condition ($F(1,69)=6.45$), $p<.05$).

Figure 3 presents the regression weights averaged over subjects for each two-way interaction term, and demonstrates that subjects were also sensitive to the correlations implied by the causal explanations. In the common-cause condition, all three two-way interactions that corresponded to common-cause causal links (a_1a_2, a_1a_3, and a_1a_4) were heavily weighted, as were all interactions that corresponded to common-effect causal links (a_1a_4, a_2a_4, and a_3a_4) in the common-effect condition.

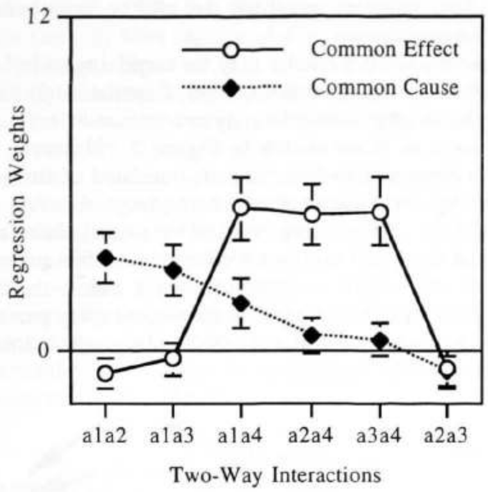

Figure 3

A 2x6x6 analysis of variance with causal pattern and category as between-subject factors, and interaction regression weight as a within-subject factor was performed. There was a significant interaction between interaction weight and causal pattern ($F(5, 345)=10.73$, $p<.0001$), indicating that the weights given to correlations were statistically different in the common-cause and common-effect conditions. A separate analysis of the common-cause condition revealed that the weights given to the common-cause correlations (a_1a_2, a_1a_3, a_1a_4) were significantly greater than weights given to irrelevant correlations ($F(1, 38)=5.93$, $p<.05$). In the common-effect condition the weights given to the common-effect correlations (a_1a_4, a_2a_4, a_3a_4) were significantly greater than weights given to irrelevant correlations $F(1, 41)=30.69$, $p<.0001$. In all cases, weights given to correlations relevant to one condition but not the other (e.g., a_1a_2 is relevant to the common-cause but not the common-effect condition) were significantly different in the two conditions.

The importance of correlations is illustrated clearly in Figure 4, which presents confidence judgments for two stimulus patterns, 0111 and 1110 (1 meaning the most-typical abnormal attribute value, and 0 the less-typical normal value). Stimulus pattern 0111 is given a lower rating in the common-cause condition because, presumably, all three common-cause causal links are violated (the cause is absent but all three effects are present) whereas only one causal link is violated in the common-effect condition. Conversely, stimulus pattern 1110 is rated lower in the common-effect condition because, presumably, all three common-effect causal links are violated (the effect is absent but all three causes are present) but only one common-cause link is violated. Note that in the common-effect condition the pattern missing a cause (0111) is rated much higher than the pattern missing the effect (1110), a result opposite of that predicted by the causal status hypothesis.

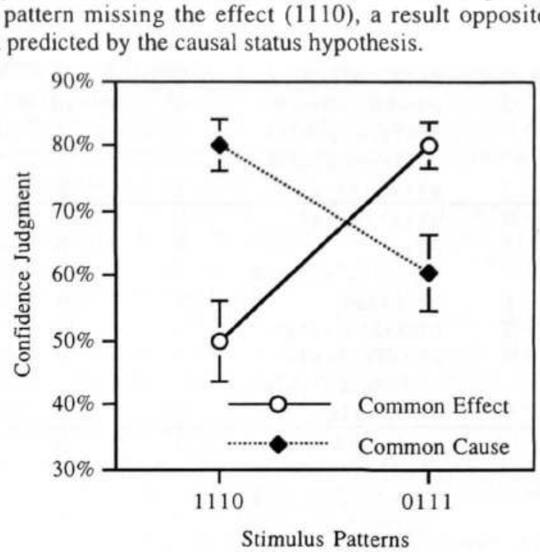

Figure 4

Note that the effects demonstrated in Figures 2, 3, and 4 must be attributed to differences in the conceptual knowledge that subjects learned in the common-cause and common-effect conditions, because all subjects were given the same statistical information, that is, the same category exemplars.

The weights given to three-way interaction terms or the four-way interaction term did not differ significantly between groups and from zero. Note that there was no effect of category in any analysis, even when more powerful single-degree-of-freedom tests of differences between kind of categories (e.g., natural kind versus artifact) were performed.

Individual Differences

Our per-subject regression analyses yielded 15 parameter estimates for each subject, and these estimates jointly characterize the strategy that a subject employed in order to make categorization judgments. A cluster analysis was performed in the 15-dimension parameter estimate space to identify groups of subjects with similar strategies. 18 clusters were identified. Table 2 presents fourteen of the most frequent and interpretable clusters, accounting for 75 (93%) of the 81 subjects. The table indicates which of the 15 regression terms had parameter estimates considerably different from zero; terms that appear in bold have substantially larger regression weights than other terms. The third and fourth columns of Table 2 indicate how many subjects employed a strategy for each causal pattern.

Clusters 1, 2, and 3 reflect strategies that did not utilize the causal information that subjects were provided. Clusters 1 and 2 reflect a family resemblance strategy in which all four attributes are weighted approximately equally, and there was no use of correlations between attributes. (The negative three-way interactions of Cluster 2 are due to floor and ceiling effects.) In Cluster 3, subjects based categorization decisions primarily on the first and fourth attribute.

Cluster	Strategy	# of Common Cause Subjects	# of Common Effect Subjects
1	a1+a2+a3+a4	9	7
2	**a1+a2+a3+a4** -a1a2a3-a1a2a4 -a1a3a4-a2a3a4	4	10
3	**a1**+a2+a3+**a4**	1	2
4	**a1**+a2+a3+a4	5	0
5	**a1**+ a1a2+a1a3+a1a4	4	0
6	a2+a3+a4	4	0
7	a1a2+a1a3+a1a4	4	0
8	**a1**+a2+a3+a4+ a1a2+a1a3+a1a4	2	0
9	**a1**+a2+a1a2	2	0
10	a1a4+a2a4+a3a4	0	5
11	a1+a2+a3+**a4**+ a1a4+a2a4+a3a4 -a1a2a4-a1a3a4 -a2a3a4	1	4
12	a1+a2+a3+**a4**+ a1a4+a2a4+a3a4	1	7
13	a1+a2+a3	0	2
14	a4+ a1a4+a2a4+a3a4	0	1

Table 2

Clusters 4-9 are interpretable as strategies appropriate to the common-cause condition. In Cluster 4 subjects utilized all attributes, but weighted the common-cause most heavily. In Cluster 5, they utilized the common-cause and correlations with its effects. In Cluster 6, only the effects were weighted, whereas in Cluster 7 only the common-cause correlations were weighted. In Cluster 8, the common-cause, its effects, and the correlations all influenced the categorization decision. In Cluster 9 the subjects attended to the first two attributes and the correlation between them.

Clusters 10-14 represent common-effect strategies. In Cluster 10, only correlations between the common-effect and its causes were weighted. In Clusters 11 and 12 the common-effect, its causes, and correlations between the two all were utilized. In addition, in Cluster 11 subjects apparently employed a complex multi-attribute strategy in which an exemplar would tend to be classified as a member of a common-effect target category only if it possessed the common-effect feature and *one* cause, apparently requiring the effect to be *justified* by the presence of at least one cause. In Cluster 13 only the causes of the common-effect were considered, and in Cluster 14 the common-effect and the correlations with its causes were utilized.

Discussion

Contrary to the predictions of the causal status hypothesis, subjects in the common-effect condition weighted the effect more heavily than the causes in making categorization decisions. Of 19 (out of 42) common-effect subjects that clearly made use of the causal link information that was provided, only two weighted the causes more heavily than the common-effect, whereas 11 weighted the common-effect more heavily. In the common-cause condition subjects did weight the cause more heavily than the effects on average. However, this strategy was not adopted by all common-cause subjects. Of 21 (out of 39) common-cause subjects that clearly made use of the causal link information, only 13 subjects weighted the common-cause more heavily than the effects. Four subjects weighted the effects more heavily than the common-cause.

The common-effect results may be surprising in light of the fact that Ahn and Lassaline (1996, Experiment 2) found causes to be weighted more heavily in common-effect causal patterns such as those shown in Figure 5. However, the exemplars presented to their subjects consisted of attributes that made up three-element subchains (e.g., A1, A2, and A3). The form of reasoning invoked for causal chains may be different than that invoked for common-effect patterns, even when the chain is embedded in a common-effect pattern. Another difference is that the present study provided subjects with some detail concerning how one attribute caused another (see Appendix).

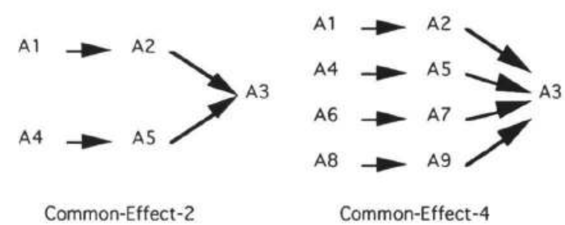

Figure 5

On the surface, our results suggest that feature importance may be a function of the number of relations in which a feature participates (Gentner, 1989). On this view, the common-effect is weighted more heavily because it participates in three causal relations whereas its causes participate in only one. However, our results indicate that some people also take into account higher-order configural information such as correlations when making categorization decisions. Ten common-cause subjects and 17 common-effect subjects made use of correlations between causes and effects. Four common-effect subjects engaged in a multi-attribute strategy that required the effect to be justified by at least one cause. Thus, assigning roles of cause and effect to attributes has more far-reaching consequences on categorization than just changing the weights given to the attributes.

We have interpreted the two-way interaction terms of our per-subject regression analyses as indicating whether the individual was detecting violations of correlations. Under this interpretation, a violation occurs whenever a cause is absent and an effect present, or a cause is present and the effect absent. In fact, people may differ about when a cause-effect relationship is violated: (a) when the cause is present and the effect absent (an "unfulfilled cause"), (b) when the cause is absent and the effect present (an "unexplained effect"), (c) when the cause or the effect is absent, and so on. The present results do not allow us to determine which notions of violation our subjects were employing. We are currently in the process of testing more elaborate stimulus sets that will allow us to answer this question.

We found that the kind of category (biological kind, nonliving natural kind, or artifact) had no effect on how attributes and attribute pairs were weighted during categorization, and did not interact with causal pattern. This null result supports an approach to categorization that emphasizes the roles of causal relations as opposed to the "kind of kind". Note that the power of our tests involving kind of category were capable of detecting effects of moderate size or larger. However, the actual effect sizes of effects involving kind of category were typically quite small ($\eta^2<.01$). Thus, the current study indicates that effects of kind of category, if present at all, are small.

One of the most important findings of the present study is that our subjects employed such a wide range of strategies when making categorization decisions. Thus, characterizing average performance at the group level may not be a useful approach in this domain. Instead, a collection of models which identify the parameters responsible for determining which strategy an individual adopts (see Nosofsky, Palmeri, & McKinley, 1994) may be necessary to fully understand the roles of causes and effects in categorization.

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Appendix

	Explanation of Causal Link
A1→A2	Blood high in iron sulphate causes a hyperactive immune system. The iron sulphate molecules are detected as foreign by the immune system, and the immune system is highly active as a result.
A1→A3	Blood high in iron sulphate causes thick blood. Iron sulphate provides the extra iron that the ant uses to produce extra red blood cells. The extra red blood cells thicken the blood.
A1→A4	Blood high in iron sulphate causes faster nest building. The iron sulphate stimulates the enzymes responsible for manufacturing the nest-building secretions, and an ant can build its nest faster with more secretions.
A2→A4	A hyperactive immune system causes faster nest building. The ants eliminate toxins through the secretion of the nest-building fluid. A hyperactive immune system accelerates the production of nest-building secretions in order to eliminate toxins.
A3→A4	Thick blood causes faster nest building. The secreted fluid is manufactured from the ant's blood, and thicker blood means thicker secretions. Thicker secretions mean that each new section of the nest can be built with fewer applications of the fluid, increasing the overall rate of nest building.