Brief article

Conditional reasoning, causality, and the structure of semantic memory: strength of association as a predictive factor for content effects

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Abstract

Available evidence indicates that responses to conditional inferences using concrete causal premises is affected by the relative number of available alternate causes (Cummins, D.D., 1995. Memory and Cognition 23 (5), 646–658). We propose that another important factor that may influence the kinds of inferences made to causal conditionals is the relative strength of association between such causes and the consequent term. We present a study with adult participants that examines the effect of strength of association on performance on a conditional reasoning task using causal premises for which there exist one highly associated potential cause for the given consequent term. We predicted that adults would produce a greater proportion of biconditional responses to invalid forms with strongly associated premises than weakly associated ones, while valid forms would not be affected by strength of association. The results are consistent with this hypothesis. © 1998 Elsevier Science B.V. All rights reserved

Keywords: Conditional reasoning; Inference; Content; Semantic memory; Causality

1. Introduction and background

Conditional reasoning is considered by many as the cornerstone of deductive reasoning and has been the subject of an important amount of research. This kind of reasoning consists in making an inference on the basis of a major premise of the type ‘if P, then Q’ (the first clause, P, is called the antecedent, the second, Q, is called

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1. Introduction and background

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the consequent). There are four basic ways by which a major premise can be extended by a minor premise. Each one corresponds to the affirmation or the negation of one or the other clause of the major premise. Among the four forms of logical problems to which it gives rise, the affirmation of the antecedent (‘P is true’), Modus Ponens (MP), and the denial of the consequent (‘Q is false’), Modus Tollens (MT), lead to certain conclusions. For example, assuming the truth of the following proposition ‘if it rains, then street is wet’ authorizes the conclusion that ‘if it rains’ then it is certain that ‘the street is wet’ and ‘if the street is not wet’ then ‘it is not raining’.

The two other logical forms consisting in the Denial of the Antecedent, ‘P is false’ (DA) and the Affirmation of the Consequent, ‘Q is true’ (AC) are uncertain arguments because they do not allow certain conclusions. For example, the denial of the antecedent (DA), ‘it is not raining’, does not permit the certain conclusion that ‘the street is not wet’ since it is possible that something other than rain can cause the street to be wet. Similarly, knowing that ‘the street is wet’ (AC) does not permit the certain conclusion that ‘it has rained’ for the same reason.

Recent studies seem to support the idea that people’s knowledge about the nature of the proposed relation between P and Q has a considerable influence on the way that they reason. There is evidence that, at least for some premises, even adult participants tend to produce biconditional inferences to AC and NA which involve drawing certain conclusions for these logical forms (Knifong, 1974; Markovits, 1985). One factor that appears to influence whether or not adults produce such responses concerns their possible access to cases of [not-P and Q] (Markovits, 1984; Thompson, 1994). More specifically, Cummins (Cummins et al., 1991; Cummins, 1995) has found that, for conditional propositions involving causal content, the tendency of reasoners to give biconditional inferences to AC and DA is related to the number of alternative causes [not-P] that can also lead to the effect Q that are available in the reasoner’s knowledge base. The authors explain these results as reflecting the use of naïve causal theories which form the basis for generating such alternative causes. Nevertheless, this perspective still leaves open the question of the specific link between this mechanism and reasoning performance.

In the following, we present a specific mechanism which can explain the effect of numbers of available alternative causes on reasoning with the uncertain logical forms and look at a specific prediction based on this. This theory was elaborated in a developmental context (Markovits, 1993) and is based on the mental models theory of Johnson-Laird (Johnson-Laird, 1983; Johnson-Laird and Byrne, 1991) which assumes that reasoners create internal representations of the premises, and that conclusions that are derived from these are dependent on the specific characteristics of these internal models. The model has been used to explain a variety of developmental phenomena in conditional reasoning (Markovits and Vachon, 1990; Markovits et al., 1996, 1998).

According to mental models theory (Johnson-Laird, 1983; Johnson-Laird and Byrne, 1991), the subject facing a conditional reasoning task creates an internal representation of the initial premise in a model including a minimal amount of information. For example, presented an ‘If P then Q’ proposition, a reasoner will first build a model similar to this one:
in which the symbol (…) represents the possible adjunction of other models to the initial model. When necessary, the initial representation is enriched with supplementary models, a process which is referred to as ‘fleshing-out’. Markovits (Markovits and Vachon, 1990; Markovits, 1993; Markovits et al., 1996) has suggested that ‘fleshing-out’ could be the result of automatic information activation in semantic memory. To be more precise, it is presumed that presented with concrete content representing an ‘If P then Q’ relation, a reasoner will attempt to activate information in semantic memory that corresponds to possible cases of [A and Q] (i.e. a case in which Q is true even if P is false). If no such information is sufficiently strongly activated during the reasoning process, developmental evidence suggests that the reasoner will flesh out the original model as an effective biconditional (Knifong, 1974; O’Brien and Overton, 1980), as follows:

\[
\begin{align*}
P & \quad Q \\
\text{not} \quad P & \quad \text{not} \quad Q
\end{align*}
\]

With such a model, reasoners will tend to respond to both AC and DA with responses of certainty.

However, if a case of [A and Q] is retrieved from memory this will be incorporated into the overall model, leading to the following:

\[
\begin{align*}
P & \quad Q \\
\text{not} \quad P & \quad \text{not} \quad Q \\
A & \quad Q
\end{align*}
\]

With such a model, reasoners will tend to respond to both AC and DA with uncertainty.

The probability of activating and retrieving at least one case of [A and Q] would increase as a function of the number of alternatives that are accessible in long-term memory. Specifically, in the case of causal conditionals, participants would activate ‘ways of making Q happen’ that were different from P. Such activation would necessarily rely on an internal causal structure (i.e. corresponding to a causal theory, cf. Cummins, 1995). Developmental evidence is consistent with the idea that the reasoning process entails both accessing an appropriate causal structure and then activating specific instances within this structure (Markovits et al., 1998).

Now, this approach generally supposes that a key element in the kinds of inferences that reasoners make is the way that information is stored in semantic memory. It is assumed that participants will attempt to activate instances of [A and Q], and that this process is subject to variation due to the structure of this information. One key component in memory structures concerns strength of activation. Specifically, suppose that a reasoner is given a causal ‘If P then Q’ conditional as a basis for reasoning. We assume that they will access a causal structure that corresponds to ‘ways of making Q happen’. Within this structure, there will be possible causes that
will be more strongly associated with the marker corresponding to the causal category. Thus, all things being equal, the presence of a more strongly associated element within a given causal structure will increase the probability of this element being sufficiently strongly activated to be included in the models used for reasoning. Studies cited previously (Cummins et al., 1991; Cummins, 1995) have used the number of alternative antecedents as a measure of response tendencies in making conditional inferences. Our analysis suggests that another important factor that may determine responses to conditional inferences is the associative strength of these antecedents to the given consequent.

Our specific model leads to the following prediction. Suppose that within a causal structure corresponding to ‘ways of making Q happen’, that one possible cause (which we will refer to as S) is most strongly associated with this category (i.e. is most strongly activated by the description of the causal category), while at least one other, W, is less strongly associated. Now, suppose that we ask reasoners to generate inferences on the basis of the following two premises:

If S then Q.
If W then Q.

Now, although the consequents of the two premises are identical, the difference between the antecedent terms has clear implications. Specifically, since S and Q are strongly associated, premise 1 would rate higher on such factors as familiarity than premise 2. Familiarity (Markovits, 1986) tends to increase the tendency to respond in ways that correspond to normative logic. Thus, to the extent that such factors affect reasoning, one would expect participants to be able to more easily produce uncertainty responses to the two uncertain logical forms AC and DA to premise 1 than to premise 2. However, our model makes a different prediction. According to this, with both premises reasoners will attempt to activate and retrieve ‘ways of making Q happen that are different from the given antecedent’. However, reasoners given premise 2 will be able to activate S as a possible case, while for premise 1, they will have to activate some other less closely associated term. Thus, we would predict that reasoners will find it easier to produce uncertainty responses to premise 2, that is that responses will be consistent with classical logic to a greater extent for premises for which the relation between the antecedent and the consequent is weaker.

Note that a similar analysis was used by Markovits et al. (1998) to examine developmental patterns of reasoning with class-based premises of the same two types. In this study, hypothesized differences were obtained for younger participants, but not for older ones. Markovits et al. (1998) explain this by the relative ease of access to alternatives furnished by premises that refer to specific classes (e.g. things that have a motor). Older children have more efficient retrieval processes and can thus more easily retrieve less highly activated cases when specific classes are referenced. However, results using causal premises show that adults have difficulties in generating uncertainty responses to the uncertain forms (Cummins et al., 1991). This suggests that adults may have difficulties in activating and retrieving relevant
alternatives within a causal structure, and that the difference between strongly and weakly associated premises should affect adult performance in the hypothesized way. Specifically, we predict that more uncertainty responses will be produced for AC and DA for the weakly associated premises. Cummins (Cummins et al., 1991; Cummins, 1995) also observed that performance on MP and MT is not affected by numbers of alternatives, but only by numbers of potential disabling conditions. Since the two premise types used here manipulate access to alternatives, it follows that no difference should be observed between the two types of premise when reasoning on MP and MT.

In a pretest, we asked participants to write as many potential causes as they could for each of nine causal consequents (effects) within 30 s. After analyzing the response patterns, we retained the four consequents for which participants had produced relatively few alternatives (in order to have items for which relatively few responses of uncertainty would be produced) and for which one specific cause was clearly strongly associated to the consequent. With these contents, we then created two types of premises by varying the antecedents and keeping the same consequents: on one side, strongly associated premises including the antecedent that appeared the more frequently in the pretest; on the other, weakly linked premises including less frequently cited antecedents.

2. Pretest

2.1. Method

2.1.1. Participants

A total of 25 first-year students in psychology were enrolled for the pretest.

2.1.2. Material

Every participant received a 10-page booklet. On the first page they received the following instructions:

‘Do not turn this page before the experimenter gives you the signal. On every one of the following pages, you will find a state of affairs for which you will have to give as many causes as you can in a limited time. Please write every possible cause on a separate line below the statement. The experimenter will tell you when to turn each page.’

At the top of every one of the following pages was written a statement describing a state of affairs such as: ‘A dog scratches constantly’. Half of the participants received a version in which contents were presented in a given order while, for others, contents appeared in the inverse order.

2.1.3. Procedure

Booklets were distributed in the classroom at the beginning of a regular course.
After the experimenter read the instructions in a loud voice and answered questions of the participants, he gave the signal to begin. Participants had 30 s to write down their answers for each statement.

2.2. Results

We established the relative frequency of appearance of every cause written by participants for a particular situation. We needed contents allowing possible causes among which one in particular was strongly associated to the consequent. Table 1 presents the four situations that were retained for the experiment along with the relative frequency of alternative causes.

3. Method

3.1. Participants

A total of 193 first-year university students (average age: 26.91 years; 52 men, 141 women) took part in this study.

3.2. Material

Eight booklets of three pages were constructed. On the first page of each booklet, participants read the following instructions:

‘In the following pages, you will have to answer a few questions. At the top of each page, a statement will be written THAT YOU MUST SUPPOSE TO BE ALWAYS TRUE. Reasoning problems referring to this affirmation will follow. Your task is to circle the letter corresponding to the answer you judge to be the good one among the three possible choices. Read attentively and answer as best you can.’

On the top of the second page was presented a conditional premise (If P, then Q) preceded by the instruction: ‘You must consider it to be always true that:’. This

Table 1
Relative frequencies of appearance for the four most frequently mentioned possible causes for each of the four chosen consequents

<table>
<thead>
<tr>
<th>Cause</th>
<th>A dog scratches constantly</th>
<th>Someone’s finger is bleeding</th>
<th>Someone’s pupils are dilated</th>
<th>A film becomes black after development</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fleas (100%)</td>
<td>Cut (88%)</td>
<td>Light (92%)</td>
<td>Expousion to light (72%)</td>
<td></td>
</tr>
<tr>
<td>Skin disease (32%)</td>
<td>Bite (36%)</td>
<td>Emotion (52%)</td>
<td>Expired film (20%)</td>
<td></td>
</tr>
<tr>
<td>Nervous tick (28%)</td>
<td>Sting (20%)</td>
<td>Drugs (20%)</td>
<td>Camera adjustment (4%)</td>
<td></td>
</tr>
<tr>
<td>Soap residue (8%)</td>
<td>Crushed (4%)</td>
<td>Eye drops (4%)</td>
<td>Wrong chemicals (4%)</td>
<td></td>
</tr>
</tbody>
</table>

Causes are given in order of frequency (%).
premise was followed by four multiple-choice questions. These questions correspond to the four logical forms of conditional reasoning. For every question, there were three possible answers:

(a) It is certain that $X$ is true.
(b) It is certain that $X$ is not true.
(c) It is not certain if $X$ is true or not.

The third page was identical to the second except that a different premise was used. To control an eventual order effect, half of participants received a version in which premises were presented in the inverted order.

For the same purpose, presentation order of questions referring to a same premise was inverted for half of the participants. They appeared one time in the following order: MP, AC, MT, NA; and in this order the other time: NA, MT, AC, MP. To be more precise, a total of eight premises were used. Because each booklet contains two of these premises and of the order effect controls, eight different booklets were distributed to the participants. Among these eight versions, the first four belong to the ‘strongly associated’ condition and the next four to the ‘weakly associated’ condition. The premises used in the strongly associated condition were the following:

(a) If a dog has fleas, then it will scratch constantly.
(b) If someone cuts his finger, then his finger will bleed.
(c) If there is a drop in the intensity of light, then the pupils of the eyes will dilate.
(d) If a photographic film is exposed to light, then it will darken during development.

Premises used in the weakly associated condition were the following:

(a) If a dog has a skin disease, then it will scratch constantly.
(b) If someone pricks his finger, then his finger will bleed.
(c) If someone takes a psychotropic drug, then the pupils of the eyes will dilate.
(d) If a photographic film is expired, then it will darken during development.

3.3. Procedure

The different booklets were randomly given out to students during regular class time. No time limits were imposed.

4. Results

Table 2 indicates the average number of conditional responses for every one of the four logical forms (MP, AC, MT, NA) in both experimental conditions. For the two uncertain forms, AC and DA, responses of uncertainty are considered to be ‘conditional’, while for the two other forms, MP and MT, ‘conditional’ responses are
responses of certainty. Note that very few participants gave an inverted response to any of the four logical forms (e.g. P is true, thus Q is false). Thus, only two of the three possible response choices were generally used for these problems.

Log-linear analyses were used to compare performance for each of the four logical forms, with the number of conditional responses as dependent variable and the premise type (strongly vs. weakly associated) as the independent variable. This revealed a significant difference between premise types in the mean number of conditional (uncertainty) responses to AC, $\chi^2(2, N = 193) = 7.82, P = 0.02$, and to DA, $\chi^2(2, N = 193) = 8.49, P = 0.01$. In both cases weakly associated premises led to a higher number of uncertainty responses than did strongly associated premises. No significant effect was found for either MP, $\chi^2(2, N = 193) = 0.74, P = 0.69$, or MT, $\chi^2(2, N = 193) = 3.78, P = 0.15$. These results are thus consistent with our predictions.

5. Discussion

The results of this study support our contention that the strength of association between elements in semantic memory plays a critical role in determining specific content effects on reasoning. It appears that, both in young children using class-based premises (Markovits et al., 1998) and in adults using causal premises, reasoning is affected by changes in the content of premises that reflect the structure and organization of knowledge in long term memory.

Previous studies have concentrated on the relative number of alternate antecedents that are available in a subject’s knowledge base as a determinant of the kinds of inferences that are made using conditional premises with concrete content (Markovits and Vachon, 1990; Cummins et al., 1991; Thompson, 1994; Cummins, 1995). It seems relatively well established that considering the relative richness of a specific semantic path is an important factor in predicting performance on conditional reasoning problems. The results of the present study underline the fact that in addition to this, the strength of association between a given consequent and various available antecedents must also be considered. Finally, although these results are not in themselves conclusive, they are consistent with the general notion that at least some content effects on inferential reasoning can be explained by on-line retrieval.

<table>
<thead>
<tr>
<th>Logical form</th>
<th>Premise type</th>
<th>Strongly associated (n = 97)</th>
<th>Weakly associated (n = 96)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MP</td>
<td>1.66 (0.66)</td>
<td>1.58 (0.71)</td>
<td></td>
</tr>
<tr>
<td>MT</td>
<td>1.35 (0.79)</td>
<td>1.15 (0.81)</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>0.94 (0.83)</td>
<td>1.27 (0.81)</td>
<td></td>
</tr>
<tr>
<td>DA</td>
<td>0.97 (0.88)</td>
<td>1.31 (0.80)</td>
<td></td>
</tr>
</tbody>
</table>
of information that is susceptible to short term activation effects due to the internal structure of semantic memory.

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