‘Does pure water boil, when it’s heated to 100°C?’: The Associative Strength of Disabling Conditions in Conditional Reasoning

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Abstract

Reasoning with conditionals involving causal content is known to be affected by retrieval of alternative and disabling conditions. Recent evidence indicates that besides the number of stored conditions, the relative strength of association of the alternative conditions with the consequent term is another important factor that affects the retrieval process. In this study we examined the effect of the strength of association for the disabling conditions. We identified causal conditionals for which there exists only one highly associated disabler. With these conditionals we constructed conditional inference problems in which the minor premise was expanded with the negation of a strongly or weakly associated disabler. Results indicate that strength of association of the disabling conditions is affecting reasoning performance: Acceptance of Modus Tollens increased when there was no strongly associated disabler available.

Introduction

Conditional reasoning has attracted a lot of interest from cognitive scientists studying human reasoning. Conditional reasoning consists in making inferences on the basis of ‘if p then q’ sentences. In a conditional inference task people are usually asked to assess four kinds of arguments: Modus Ponens (MP, ‘if p then q, p therefore q’), Modus Tollens (MT, ‘if p then q, not q therefore not p’), Denial of the Antecedent (DA, ‘if p then q, not p therefore not q’), and Affirmation of the Consequent (AC, ‘if p then q, q therefore p’).

Under the material implication interpretation of standard logic, MP and MT are considered valid inferences while DA and AC are regarded as fallacies. Much of the work on conditional reasoning has tried to identify the factors that influence performance on these four problems (for a review, see Evans, Newstead, & Byrne, 1993).

A growing body of evidence is showing that peoples knowledge about the relation between the p (antecedent) and q (consequent) part of the conditional has a considerable effect on the underlying reasoning process (e.g., Byrne, Espino, & Santamaria, 1999; Markovits, 1984; Newstead, Ellis, Evans, & Dennis, 1997; Rumain, Connell, & Braine, 1983; Thompson, 1994).

In the case of reasoning with conditionals involving causal content (e.g., ‘If cause p, than effect q’) seminal work has been done by Cummins and her colleagues (1995; Cummins et al., 1991). Following Byrne (1989), Cummins examined the effect of the alternative and disabling conditions of a causal conditional. An alternative condition is a possible cause that can produce the effect mentioned in the conditional while a disabling condition prevents the effect from occurring despite the presence of the cause. Consider the following conditional:

If the brake is depressed, then the car slows down

Possible alternative conditions for this conditional are:

running out of gas, having a flat tire, shifting the gear down…

The occurrence of these conditions will result in the car slowing down. The alternatives make it clear that it is not necessary to depress the brake in order to slow the car down. Other causes are also possible.

Possible disabling conditions are:

a broken brake, accelerating at the same time, skid due to road conditions…

If such disablers are present, depressing the brake will not result in the slowing down of the car. The disablers make it clear that it is not sufficient to depress the brake

in order to slow down the car. There are additional conditions that have to be fulfilled.

When people (fallaciously) accept DA and AC inferences, they fail to see that there are other causes that may lead to the occurrence of the effect beside the original stated one. Cummins (1995) and Cummins et al. (1991) found that peoples acceptance of DA and AC inferences decreased for conditionals with a high number of possible alternative conditions. This showed that a crucial factor in making the fallacious inferences is the number of alternative causes people can think of. In addition, she found that the number of disabling conditions affected the acceptance of the valid MP and MT inferences: If there were many conditions that could disable the relation between antecedent and consequent, people tended also to reject the valid inferences.

Recently, Quinn and Markovits (1998) have identified another factor that may influence reasoning with causal conditionals. They showed that not only the number of alternative conditions is important, but also what they call the 'strength of association' of the alternative conditions. Quinn and Markovits developed a framework (see also Markovits, Fleury, Quinn, & Venet, 1998) where reasoning performance is being linked to the structure of semantic memory. In this framework it is assumed that, when confronted with a causal 'if p then q' conditional, reasoners will access a causal structure in semantic memory that corresponds to 'ways of making q happen' (i.e., alternative conditions). Within the structure, there will be causes that are more strongly associated with q than others. The more strongly associated a specific cause is, the higher the probability that it will be retrieved by the semantic search process.

Quinn and Markovits (1998) measured strength of association by frequency of generation: In a pretest, participants were asked to write down as many potential causes for a certain causal consequent (effect, e.g., 'a dog scratches constantly'). This allowed the construction of conditionals with a strongly (e.g., 'If a dog has fleas, then it will scratch constantly') and weakly (e.g., 'If a dog has skin disease, then it will scratch constantly') associated cause. With the weak conditional, reasoners will be able to activate the strongly associated cause, while they will have to activate some other, less closely associated term for the strong conditional. Thus, it will be more difficult to retrieve an alternative condition in case of the strong conditional, which would lead to a greater acceptance of DA and AC inferences. The results of the study were consistent with the predicted response pattern.

The identification of the strength of association effect raises the question whether this effect is also present for the disabling conditions. Indeed, although knowledge of disabling conditions is also stored in semantic memory, Quinn and Markovits (1998) restricted their case to an analysis of the alternative conditions. Cummins (1995) already showed that both the number of alternatives and disablers is affecting reasoning performance. In addition, Elio (1998) has shown that the process of disabler retrieval is not only important in conditional reasoning but also in the field of belief revision and non-monotonic reasoning: Belief in a conditional after contradiction was lower when people could find many disablers. Thus, both for reasoning psychologists and the psychological and AI community studying belief revision, examining the effect of associative strength of disablers can identify a new factor affecting the crucial disabler retrieval. Therefore, we examined in this study whether Quinn and Markovits' strength of association effect also generalized to the disabling conditions.

The framework developed by Quinn and Markovits (1998) was adopted and extended to the disabling conditions. It was assumed that when presented a causal conditional, people will not only access a causal structure with alternative conditions but also one that corresponds to 'ways that prevent q to occur' (see Vadeboncoeur & Markovits, 1999). When such disabling conditions are retrieved, p will no longer be perceived as a sufficient condition for q what renders the MP and MT conclusions uncertain.

In a generation task we identified strongly and weakly associated disablers for a number of conditionals. We constructed experimental items by expanding the original antecedents of the conditionals with the negation of the strongly or weakly associated disabler. Suppose that for a certain conditional we find that S is a strongly associated disabler, while W is a weak one. This allows the construction of the expanded conditionals: 'If P and not S, then Q' (strongly expanded) and 'If P and not W, then Q' (weakly expanded). These expanded conditionals have an equal number of possible disablers (i.e., the original number minus one). However, reasoners presented with 'If P and not W, then Q' will still be able to activate the strongly associated disabler S, while with 'If P and not S, then Q' they will have to activate a less closely associated one. Thus, it will be harder to access and retrieve disablers for the strong conditionals. This access-to-disablers manipulation rests solely on the strength of association of the disablers and not on the number of accessible disablers.

Retrieving disablers from semantic memory will decrease the acceptance of MP and MT inferences. Therefore, we predict that acceptance ratings for MP and MT inferences will be higher for the strongly expanded conditionals than for the weakly ones. In the present experiment we did not manipulate the access to alternative conditions. Since, Cummins (1995) findings indicate that retrieving disablers has no effect on DA and AC it follows that no difference should be observed

on DA and AC acceptance between the strong and weak conditionals.

Experiment

Pretest

The material for the present experiment was selected from previous pilot work (see De Neys, Schaeken, & d'Ydewalle, 2000), where 20 participants wrote down as many disabling conditions as possible for a set of 20 causal conditionals (with 1.5 min generation time for each conditional).

For every conditional we established the relative frequency of appearance of the disablers that participants wrote down. We needed conditionals with a set of disablers in which there was one specific disabler that was very frequently generated. The expanded conditionals manipulation also forced us to take an additional criterion into account. We could not allow disablers that express a quantification of the original antecedent (e.g., 'brake not depressed hard enough'). Expanding the original with this kind of disablers would result in inconsistencies for some problems (e.g., DA, 'The brake was not depressed and the brake was depressed hard enough'). We selected 3 conditionals that met these criteria. From each set of disablers one infrequently generated disabler was selected. This weakly associated disabler had to meet the non-quantification criterion. Furthermore, if the strongly expanded conditional contained an explicit negation (e.g., 'If the apples are ripe and they are not picked'), we opted to express the selected weakly associated disabler in an explicit negated way too. The negation criterion should guarantee that the strongly and weakly expanded conditionals have comparable lexical complexity. Finally, the selected disablers had to sound as natural (according to our intuitions) as possible (e.g., 'not too little wind' was not accepted). Table 1 presents the material that was selected for the experiment.

We note that one might utter reservations about the use of frequency of generation as a measure of strength of association. Quinn and Markovits (1998) did not address this issue. However, our pilot study showed that frequency of generation was related to other possible strength of association measures such as plausibility and generation order: More frequently generated disablers were judged more plausible and tended to be generated prior to less frequently generated ones.

Method

Participants and Material

89 first-year university students participated in the experiment. Participants received a 4-page booklet. Page one included the instructions for the task. On the top of each of the next three pages appeared the selected conditionals. Each conditional was embedded in the four inference types (MP, DA, MT, AC). So, each of the three pages included one conditional with four inference problems. For each conditional there was a specific presentation order of the four inferences (AC, MT, DA, MP or MP, MT, DA, AC or MP, DA, MT, AC). The three pages were bound into booklets in randomized order. Below each inference problem appeared a seven point rating scale. This resulted in the following item format:

Rule: If water is heated to 100°C, then it boils

Fact: The water is heated to 100°C and the water is pure
Conclusion: The water boils

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                                  I
-1--------2--------3---------4--------5--------6--------7-
very sure  somewhat sure  I somewhat sure  very sure
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That I CANNOT draw this conclusion — That I CAN draw this conclusion

Figure 1. An example of the item format

Figure 1 presents an example of the MP problem. On the same page participants would also find the MT, DA and AC problem. The access to disablers manipulation

Table 1.
Relative frequency of generation of the most frequently mentioned disablers for the three selected conditionals. The disablers are given in order of frequency (%). Selected strongly and weakly associated disablers are highlighted.

If the apples are ripe, then they fall from the tree	If John grasps the glass with his bare hands, then his fingerprints are on it	If water is heated to 100° C, then it boils
Picked (65%)	*Hands not greasy (50%)*	*No pure water (75%)*
Too little wind (25%)	Grasped glass with palms only (35%)	*No normal pressure (30%)*
Not enough weight (20%)	Prints wiped off (30%)	Bad temperature measure (30%)
Not ripe enough (20 %)	*Glass was wet (25%)*	
Apples caught in branches (10 %)		

consisted in the presentation of two different minor premises (the information under the heading 'Fact'); the above example would belong to the strongly associated group were the original information was expanded with the negation of the strongest associated disabler. Similarly, in the weakly associated group, the negation of the selected weakly associated disabler was added to the 'Fact:'-information. In both expanded groups appeared the original conditionals on top of the item pages. Thus, participants were not presented explicit expanded conditionals but rather conditional inference problems with expanded minor premises. All the items in a single booklet belonged to the same group. Table 2 gives an overview of the different material in the two groups (for an MP problem)

Table 2.
Different contents in the experimental groups. Both groups only differ by the kind of information that is presented in the minor premise.

Expanded strongly associated:
(a) Water is heated to 100°C and the water is pure (b) The apples are ripe and they are not picked (c) John grasps the glass with his bare hands and his hands are greasy
Expanded weakly associated:
(a) Water is heated to 100°C and the pressure is normal (b) The apples are ripe and they are not caught in the branches (c) John grasps the glass with his bare hands and the glass is dry

Procedure
The booklets were randomly given out to students who agreed to participate in the experiment. No time limits were imposed. The instructions explained the specific item format of the task. Participants were told that the task was to decide whether or not they could accept the different conclusions. The instruction page showed an example problem (always standard MP) together with a copy of the rating scale. Care was taken to make sure that participants understood the precise nature of the rating scale. As in Cummins (1995), participants were NOT specifically instructed to accept the premises as always true. With Cummins we assume that this encourages people to reason as they would in everyday circumstances.

Results

Participants rated each of the four inference types three times. For every inference type the mean of these three ratings was calculated. This resulted in a 4 (inference type, within-subjects) x2 (group, between-subjects) design. All hypotheses were tested with planned comparison tests and rejection probability of .05.
Table 3 shows the overall mean acceptance ratings for the four inference types in the expanded weakly and strongly associated group. Planned contrasts indicated that the acceptance ratings in both groups differed significantly [$F(1, 87) = 4.55$, $MSe = 3.85$, $p < .04$]. As expected, both expanded groups did not differ in terms of the acceptance ratings for DA and AC inferences. For MT inferences we did obtain significantly higher ratings in the strongly associated group [$F(1, 87) = 4.99$, $MSe = 2.67$, $p < .03$]. Although, the effect on MP problems was in the expected direction (higher ratings in the strongly than in the weakly associated group), it did not reach significance.

Table 3.
Mean acceptance rating for the four inference types in the strongly associated and weakly associated groups.

Inference type	Group	
	Expanded weakly associated (n=45)	Expanded strongly associated (n=44)
MP	5.7	5.92
DA	4.78	5.11
MT	4.37*	5.14*
AC	4.98	5.44

* planned contrast $p<.05$

Discussion

The study showed that the strength of association of a disabling condition is affecting the conditional reasoning process. As predicted, peoples acceptance of MT inferences increased when there was no strongly associated disabler available, while the associative strength of the disablers had no effect on DA and AC inferences. This supports the hypothesis that in addition to the number of disabling conditions (Cummins, 1995), retrieving disablers from semantic memory is affected by their strength of association.

We suspect that the non-significance of the expected effect on MP may be due to a ceiling effect on the MP acceptance ratings. In the pretest, relatively few disablers were generated (less than the overall mean) for the three conditionals that were adopted for the experiment. Cummins (1995) already obtained high MP acceptance ratings for these conditionals. The 'expansion' manipulation in the present experiment

then further decreased the available number of disablers. This may have resulted in a ceiling effect. It could be the case that MP acceptance was already at the top in the weakly associated group. Mean acceptance for MP in the weakly associated group (Mean = 5.7, see Table 3) indeed tended to the 'sure that I can draw this conclusion' rating, located at the upper end of the scale. As in Cummins (1995), acceptance ratings on the (more difficult) MT inference were lower, what allowed the associative strength effect to show up.

It is interesting to note that for all of the four inference types acceptance ratings were lower when there was a strongly associated disabler available. Although the effect on AC and DA was not significant, one could suggest that the availability of a strongly associated disabler results in an overall decrease in certainty for every inference type (and not just for MT or MP). This might tie in with recent evidence (e.g. Manktelow & Fairley, 2000) showing that acceptance of DA can be affected by disabling conditions. This issue, together with the hypothesized ceiling effect on MP, will need to be addressed in further research.

In this study we adopted Quinn and Markovits' (1998) notion of a semantic search process and extended it to the disabling conditions. We should note that Quinn and Markovits (see also Markovits et al., 1998) incorporated the postulated semantic search process in the mental models theory (Johnson-Laird and Byrne, 1991). Here we refrained from making specific claims about the nature of the basic inferential principles (i.e., mental models or mental inference rules). The general semantic search process can be incorporated in other reasoning theories like mental logic (Braine & O'Brien, 1998; Rips, 1994) or the probabilistic approach (Oaksford & Chater, 1998). Comparing these different implementations is not within the scope of the present study or the Quinn and Markovits experiment.

We mentioned the relevance of the present study for the work of Elio (1997, 1998) and other researchers in the domain of belief revision and non-monotonic reasoning. Elio established that the number of stored disabling conditions affected peoples belief revisions and stated that conditional reasoning and belief revision are guided by the same memory search process. Our results show that successful retrieval is not only affected by the number of stored disabling conditions but also by their strength of association.

The present study can also be related to the work of Chan and Chua (1994). They examined the effect of 'relative salience' of disabling conditions. This factor can be interpreted as strength of association. Chan and Chua presented participants inference problems with two conditionals (e.g., 'If p then q, If r then q, p, thus q?'). The second conditional mentioned a possible disabling condition while the categorical premise was not expanded (see Byrne, 1989). Acceptance of MP and MT decreased with the strength of association of the mentioned disabler. However, a crucial difference with our study is that the present manipulation specifically affected the retrieval of disablers from semantic memory. In Chan and Chua's experiment, reasoning was affected by the strength of association of the mentioned disabler per se. The expansion of the categorical premise in the present experiment eliminated a strongly or weakly associated disabler and thereby affected the strength of association in the residual disabler set.

In sum, our study indicated that the conditional inferences people make are influenced by the strength of association of the disabling conditions. This complements Quinn and Markovits' (1998) contention that the strength of association of elements in semantic memory is an important factor in predicting conditional reasoning performance.

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