Title
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Abstract

We suggest and test an integrated framework explaining how the interpretation of and the reasoning from causal conditionals (e.g., "If you fertilize a flower it will bloom") depend on exceptions. In the model availability of exceptional situations (e.g., "the flower was not watered enough") reduces the subjective conditional probability of the consequent given the antecedent, *P(q|p)*. The conditional probability corresponds to the subjective degree of belief in the conditional, *P(p→q)*. The degree of belief in the conditional affects the willingness to accept the valid inferences modus ponens (MP) and modus tollens (MT). Additionally to this probabilistic pathway the framework contains a mental model pathway: a direct influence of exceptional situations on the willingness to accept MP and MT. Three internet-based experiments supported the frame-work for causal but not for arbitrary conditional statements in which no meaningful relation between antecedent and consequent was present.

Introduction

Reasoning tasks constitute a mixture of interpretation and drawing a conclusion, because prior to any reasoning per se the *meaning* of the premises has to be understood and represented adequately.

In this paper we propose an integrated framework of interpretation of and reasoning from causal conditional statements. The model understands the interpretation of a causal conditional and the reasoning from the statement as distinct steps in a successive sequence with the final result of accepting or rejecting an inference. This sequence depends crucially on the availability of exceptions to the causal relation that is described in the conditional statement. The availability of exceptions has been identified as an important determinant of people's readiness to accept a conclusion by researchers emphasizing the content and context of the conditionals used as premises (Cummins, 1995; Thompson, 1994). Our model integrates this approach with probabilistic accounts of the meaning of *if* (Evans, Handley, & Over, 2003; Oberauer & Wilhelm, in press) and with variants of the mental model theory of conditional reasoning.

Towards an Integrated Model of Interpretation and Reasoning with Causal Conditionals

"If you fertilize a flower, then it will bloom" - according to recent theories in philosophy and psychology this sentence is true for a garden in which most of the flowers that have been fertilized will bloom. It is not necessary that all fertilized flowers bloom, since the conditional in everyday language does not imply a deterministic reading. A conditional statement "If *p* then *q*" conveys the meaning that the *conditional probability* of the consequent *q* given the antecedent *p*, *P(q|p)* is high. A believable conditional statement is characterized by a high conditional probability, *P(q|p)*, an unbelievable conditional by a low value of *P(q|p)*. The probabilistic approach assumes that the conditional probability *P(q|p)* is closely connected to the overall belief in the conditional statement (Edgington, 1995; Evans, Handley, & Over, 2003; Oaksford & Chater, 2001; Oberauer & Wilhelm, in press).

The conditional probability account not only allows for exceptions, e.g. fertilized flowers that do not bloom, but assigns them a crucial role. The more exceptions there are, the less believable a conditional statement becomes. We denominate as e*xceptional situations* circumstances that have the power to generate exceptions, e.g.,

- the flower has not been watered enough
- the flower suffers from varmints

Exceptional situations take on the semantic role of disabling conditions according to the terminology of Cummins (1995) for forward causal conditionals like "If you fertilize, then a flower it will bloom". For backward causal conditionals like "If a flower blooms, then it has been fertilized" exceptional situations constitute alternative causes, e.g. "the flowers grows in fertile ground".

Modus ponens (MP: "if *p* then *q*, *p* therefore *q*") and modus tollens (MT: "if *p* then *q*, *not-q* therefore *not-p*") have been shown to be suppressed in experimental conditions with unbelievable conditional premises, which means that they have lower acceptance rates than with believable premises (Cummins, 1995; Stevenson & Over, 1995; Thompson, 1994). For causal conditionals the availability of exceptional situations has been shown to suppress MP and MT (Cummins, 1995; Cummins, Lubart, Alksnis, & Rist, 1991; Thompson, 1994). With availability we mean the ease with which many different situations can be brought to mind. One obvious way to understand this finding is to assume that exceptional situations reduce the believability of the conditional premise, which in turn reduces the perceived acceptability of the conclusions.

The reflections hitherto can be integrated into the *probabilistic pathway* in the framework we suggest (see Figure 1): The availability of exceptional situations negatively affects the subjective conditional probability, $P(q|p)$, which correspond to the subjective degree of belief in a conditional, $P(p \rightarrow q)$. The degree of belief in a conditional statement has a direct impact on the willingness to accept the valid inferences MP and MT.

Markovits and Barrouillet (2002) suggested a mental model account of causal conditional reasoning. In line with the tradition of the mental models theory by Johnson-Laird (1983), the authors assume that humans reason from a set of mental models, each model representing a situation that fulfils the truth-condition of the premises. When reading or hearing a causal conditional with realistic content, relevant aspects of the context and content are automatically activated in our memory. For a causal relation exceptional situations are highly relevant and are therefore automatically activated. Hence it is likely that an exception is integrated into the current set of mental models. An exceptional situation is equivalent to a counterexample to the conclusions of the valid inferences MP and MT.

The authors assume that if a counterexample to the conclusion is present in the mental model(s) of the premises an inference will be rejected. This effect is not necessarily mediated through changes in the subjective conditional probability of *q*, given *p*, or the degree of belief in the conditional. To test this idea we include a direct inhibiting pathway from exceptional situations to the acceptance of MP and MT in our framework, which we call the *mental model pathway*.[1]

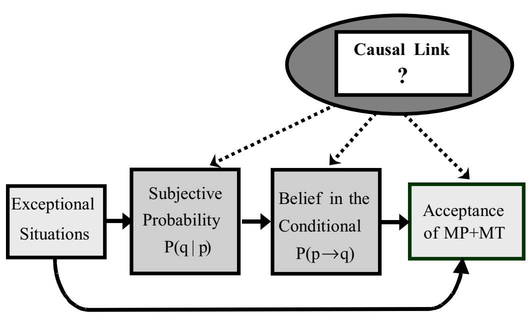

Figure 1: Integrated Framework of Causal Conditionals

The mental model account and the probabilistic account agree *that* exceptional situations have an influence on the willingness to accept a valid inference, but they do not agree on *how* this influence is exerted. The relative merits of the two families of theories can be assessed by estimating the relative weights of the direct and the indirect pathway in our framework.

The framework is in agreement with available results in the literature obtained with causal conditionals (e.g., Cummins et al., 1991; Thompson, 1994). But what about *arbitrary* conditionals? In arbitrary conditional statements there is no link between antecedent and consequent other than that expressed in the "if...then" statement itself, e.g. "If dogs know how to swim, then Greenland is inhabited". In agreement with other researchers, we suspect that arbitrary conditionals are fundamentally different from causal ones (Cheng & Holyoak, 1985; Markovits & Barrouillet, 2002; O'Brien, Costa, & Overton, 1986; Peel, 1967).

Even if two conditionals shared the same conditional probability $P(q|p)$, the presence or absence of a causal link could make a psychological difference for how conditionals are understood, and how inferences are drawn from them. For our experiments we varied this factor by using the very same conditionals once in a context pointing out a causal link between antecedent and consequent (causal conditionals) and once in a context providing no link at all (arbitrary conditionals).

Experiments

The main goal of the experiments reported here was to test the integrated framework experimentally. A second goal was to explore the role of causal links between antecedent and consequent in conditionals. Therefore, we compared the same conditionals with forward causal links (i.e., if cause, then effect), backward causal links (i.e., if effect, then cause)[2], and without causal link between antecedent and consequent.

To achieve the latter goal we embedded the same wording of a conditional statement in slightly different cover stories. An experimental item consisted of a cover story plus a conditional statement. To test our framework, we computed a path analysis over experi-

[1] Another revised mental model theory that yields the same prediction was recently suggested by Schroyens and Schaeken (2003).

[2] For the sake of brevity and clarity we abstain here from reporting theoretical considerations and empirical results on the differences between forward and backward causal conditionals.

mental items.

In Experiment 1 participants estimated the conditional probability of the consequent q given the antecedent p, that is $P(q|p)$. In Experiment 2 they estimated the degree of belief in a conditional, that is, the probability of the conditional being true, $P(p \rightarrow q)$. Additionally all participants in Experiments 1 and 2 rated the availability of exceptional situations. In Experiment 3 participants solved conditional reasoning problems.

Method

Participants and Material. The experiments were conducted through the internet. 205 and 230 people participated in Experiments 1 and 2, respectively, and 1068 in Experiment 3.

Each item consisted of a pseudo-naturalistic cover story followed by a conditional statement, e.g., *If a dog suffers from Midosis then one finds Xathylen in its blood*. For each conditional statement we created three slightly different cover stories. The basic paradigm was adapted from Waldmann (2001). We used two sorts of causal stories (implying forward and backward direction of causality) and a neutral cover story introducing the conditional as an *arbitrary* connection between two elementary propositions. The word "cause" was not used in any of the cover stories.

The critical passage of one story with forward causal link was:

> A laboratory in Australia has recently discovered a new allergic disease in dogs. The new disease has been named Midosis. [...] The scientists have detected that the disease makes an affected dog's blood produce the formerly unknown substance Xathylen.

Following this cover story a protagonist uttered the conditional as a hypothesis. The protagonist was always unrelated to the former story, for example:

> Sara is a practicing veterinarian. She assumes that it generally holds that:
> "If a dog suffers from Midosis
> then one finds Xathylen in its blood".

The second causal cover story for the same conditional was almost identical to the first, but instead of Midosis producing Xathylen, the story explained that Xathylen is the substance that leads to the symptoms of the allergic disease Midosis. The critical passage read:

> In the blood of the affected dogs, a formerly unknown substance called Xathylen is produced. This substance leads to the multiple symptoms of Midosis.

The causal roles of the two events are reversed, instead of "If cause then effect" the conditional now had the form "If effect then cause".

The neutral cover story for the arbitrary conditionals was similar to the causal stories. The major difference was that the story did not suggest any causal link between Midosis and Xathylen. The critical passage read as:

> The laboratory has recently discovered a new allergic disease in dogs called Midosis. A different department has detected a formerly unknown substance in the blood of cats and has named it Xathylen. During the last weeks the scientists explored whether Xathylen is found in dog's blood as well.

Nine scenarios were used embedding conditionals with very different matters, e.g., biological, physical, and social relations. With a large variety of scenarios we hoped to provide a fair test for a general model. The combination of nine conditionals with three cover stories resulted in a total of 27 different combinations of conditional statement plus cover story. To control for differences in the order of the terms in the conditional statement, we furthermore used both possible orders of terms in the conditional statement: "If Midosis then Xathylen" as well as "If Xathylen then Midosis". Therefore our item pool consisted of 54 items. All materials were written in German.

Procedure. In Experiments 1 and 2 each participant received six items (two forward items, two backward items, and two arbitrary items), each from different scenarios, randomly selected. The items were presented in random order, each one on a separate screen. Each item consisted of a cover story, the conditional, and four questions. Participants in Experiment 1 estimated the conditional probability of the consequent given the antecedent, $P(q|p)$:

> A dog is randomly selected from the lab's kennel.
> It turns out that this dog suffers from Midosis.
> How likely do you think it is that one finds Xathylen in its blood?

Participants in Experiment 2 estimated the probability of the conditional being true, $P(p \rightarrow q)$, instead. This is the subjective degree of belief in a conditional. For example:

> How likely do you think it is that Sara's statement holds true?

It was explained that the estimate should be given on a scale from 0 ("totally impossible") to 100 ("absolutely certain").

We asked participants for an estimate of the availability of exceptional situations in both

Experiments 1 and 2. The question read:

> For the next question please assume that Sara's statement is true. Can you imagine conditions under which the following instance is possible?
> A dog suffers from Midosis, but no Xathylen is found in its blood.

Participants indicated how many conditions they could think of on a 5-point rating scale from "very few" to "very many", with an additional option provided "No, I cannot imagine such a situation". To ensure that participants carefully considered the conditions, we asked them to describe one situation in short keywords.

Furthermore, in Experiments 1 and 2 there was a rating of the perceived causal strength and a rating of the availability of alternative situations (cases of *q* but *not-p*).

In Experiment 3 participants solved conditional reasoning problems. One group of participants decided whether the conclusion followed from the statements with logical necessity (*logic instruction*, $n = 569$). Another group decided whether they would accept the conclusion within an everyday conversation context (*plausibility instruction*, c.f. Rips, 2001, $n = 499$). In both instructions it was stressed that the relation in an *if*-sentence is not necessarily reversible. Each participant then received three items (one forward, one backward, and one arbitrary item). Each item was followed by four inference problems with forced choice answers (*Yes* or *No*): MP, MT, AC (acceptance of the consequent, "if *p* then *q*, *q* therefore *p*") and DA (denial of the antecedent, "if *p* then *q*, *not-p* therefore *not-q*")[3]. To control for order effects we used two orders of inferences: MP-AC-MT-DA or DA-MT-AC-MP. Within each participant order of inferences was held constant.

Results

In order to test our framework for conditionals we conducted a path analysis on the correlations over items. For each of the 54 items mean values of estimates for the variables in the model were computed (for an overview over the means and standard deviations see Table 1).

We had different groups of participants estimate the conditional probability, the probability of the truth of the conditional, and the acceptability of the four inferences, in order to avoid transfer effects within participants that would artificially increase the correlations between these variables. Therefore, we could compute correlations between these variables not across participants, but only across items. One consequence of this is a relatively small sample size of items. We hoped to compensate this by highly reliable estimates of correlations, since each data point rests on aggregated responses from 20-30 participants.

We fitted the path model depicted in Figure 2 to the overall data, allowing different path coefficients for the causal statements (taking forward and backward causality together) and the arbitrary statements. Figure 2 displays the standardized path coefficients and the R^2 values for the dependent variables for the causal sub-model. The overall X^2-value indicated an acceptable model fit ($X^2 = 29.77$, df = 22, p = 0.18) as did the RMSEA index (RMSEA = 0.08)[4]. The model fit to the *causal* conditionals alone had a good fit ($X^2 = 10.6$, df = 11, p = 0.48; RMSEA = 0.00). Furthermore, inspection of Table 2 reveals that for the causal conditionals all path coefficients except one were significantly larger than zero.

For the model with the *arbitrary* conditionals only, the model fit is not convincing ($X^2 = 19.8$, df = 11, p = 0.06; RMSEA = 0.21). Among the few paths that received significant coefficients are those connecting exceptional situations, subjective conditional probability, and the degree of belief in the conditional, that is the first steps in what we called the "probabilistic pathway" above.

The emphasis on *logic* versus *plausibility* in the instruction had a small but reliable effect on the reasoning performance. In the logic group there were about 5 % more answers in agreement with the normative standard of material implication. Thus,

Table 1: Means and Standard Deviations for Variables in the Model (for Abbreviations see Figure 2)

	Conditionals	
Variable (from Exp. 1-3)	Causal ($n = 36$)	Arbitrary ($n = 18$)
Exceptional Situations (0-5)	1.92 (0.59)	2.33 (0.66)
Subjective Probability	74.0 (12.2)	55.8 (17.0)
Belief in the Conditional	66.0 (15.4)	38.7 (18.0)
MP_L	80.9 (13.8)	73.0 (15.5)
MT_L	56.7 (14.5)	49.1 (15.9)
MP_P	72.6 (15.1)	63.1 (14.8)
MT_P	57.8 (15.9)	43.6 (11.0)

Note. Subjective Probability and Degree of belief in the conditional were estimated on a scale from 0 to 100. For the inferences percentage of YES-answers are displayed (max. 100).

[3] It can be suggested that the framework proposed here for MP and MT inferences can be transferred symmetrically to AC and DA inferences by replacing exceptional situations through alternative situations and exchanging *p* and *q* in all variables.

[4] RMSEA < 0.05 indicates a good fit, RMSEA < 0.08 indicates an acceptable fit. RMSEA > 0.10 displays a poor fit.

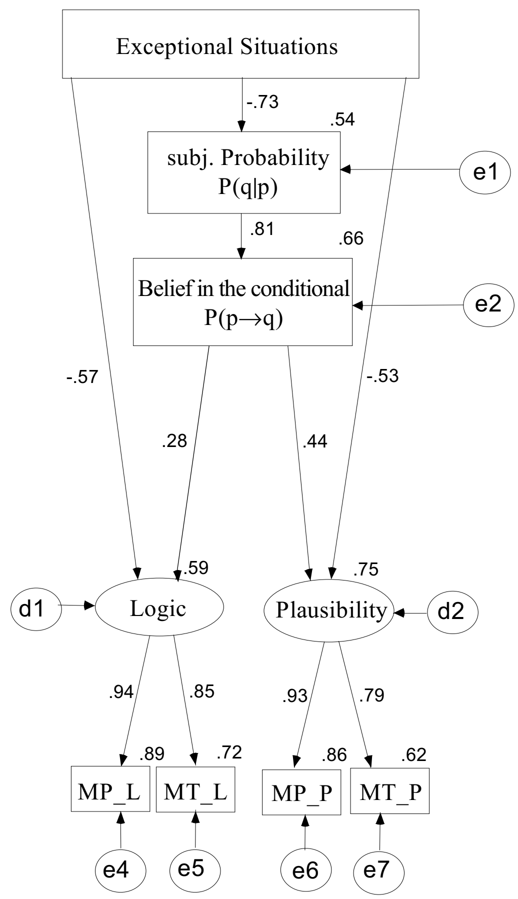

Figure 2: Structural equation model and standardized results for the causal conditionals. "Logic" is a latent variable defined by the proportion of participants in the group instructed to reason logically who accepted MP and MT. "Plausibility" is the corresponding latent variable for the group instructed to assess the argument's plausiblity.

participants were sensitive to the difference in the instructions. Nonetheless, in the results of the structural equation models no difference between the instruction groups is apparent. The left side of the path diagram, with inferences from the logic instruction group as dependent variables, does not differ from the right side, where the dependent variables are inferences drawn in the plausibility instruction group. When the probabilistic pathway and the mental model pathway for the *logic* group were fixed to be equal to the corresponding paths for the p*lausibility* group, the overall model fit decreased only negligibly (X^2 = 31.5, df = 26, p = 0.21; RMSEA = 0.06). With this plausible constraint, the pattern of path coefficients is clear-cut: For the causal conditionals all path coefficients received significant weights. For the arbitrary conditionals all path coefficients received significant weights except for the paths from the belief in the conditional to the latent variables "Logic" and "Plausibility" that correspond to the proportions of participants that accepted the inferences MP and MT.

The path coefficients between exceptional situations, conditional probability, and the belief in the conditional, that is the first steps in the probabilistic pathway, can be constrained to be the same in both models (causal and arbitrary) without any loss of fit.

Interestingly, the described patterns of results do not change if we swap the roles of subjective conditional probability and degree of belief in the conditional within the framework.

General Discussion

We developed and tested an integrated framework bringing together probabilistic, semantic, and mental model theories on the interpretation of and the reasoning from causal conditional statements.

The model was supported for causal conditionals, but not for arbitrary conditionals. The analysis for causal conditionals yielded significant weights for the indirect

Table 2: Standardized Path Coefficients and *p*-Values for Causal and Arbitrary Items

Path			Causal Items (*n* = 36)		Arbitrary Items (*n* = 18)	
			Estimate	*p*	Estimate	*p*
Exceptional Situations	-	Subjective Probability	-0.73*	0.00	-0.54*	0.01
Subjective Probability	-	Belief in the Conditional	0.81*	0.00	0.85*	0.00
Exceptional Situations	-	Logic	-0.57*	0.00	-0.08	0.68
Belief in the Conditional	-	Logic	0.28	0.07	0.30	0.13
Exceptional Situations	-	Plausibility	-0.53*	0.00	-0.76*	0.00
Belief in the Conditional	-	Plausibility	0.44*	0.00	-0.01	0.95
Logic	-	MP_L	0.94	(fixed)	1.19	(fixed)
Logic	-	MT_L	0.85*	0.00	0.66	0.15
Plausibility	-	MP_P	0.93	(fixed)	0.69	(fixed)
Plausibility	-	MT_P	0.79*	0.00	0.89*	0.01

Note. * p > 0.05

probabilistic pathway as well as for the direct mental model pathway. This supports the interpretation that for causal conditionals both families of theories are warranted, they are not mutually exclusive. This raises the question how to reconcile the two groups of theories. At the moment, we can only speculate about this question. Reasoning from a conditional statement is different from evaluating a conditional's believability or its truth. A major difference is that a minor premise comes into play as well. With reference to recent findings of Markovits and Potvin (2001) it is plausible to assume that representing a minor premise (re)-activates the whole knowledge structure in semantic memory associated with the conditional statement. Exceptional situations are part of this knowledge structure and this additional activation through the minor premise could explain why the availability of exceptional situations has an effect on reasoning that is independent from its effect on the believability of the conditional statement.

The model for the arbitrary conditionals differed from the model for causal conditionals in two major aspects. First, the model fit for the arbitrary items was poor. Second, after the direct effect of exceptional situations on the acceptance of MP and MT was partialled out, there was no significant effect mediated through subjective probabilities. If this finding turns out replicable, it would contradict the probabilistic theory of conditional reasoning (Oaksford & Chater, 2001). The observed differences between causal and arbitrary conditionals encourage further research about the role of a semantic link between antecedent and consequent in conditionals.

The present empirical test of the suggested framework is based only on correlational data. In follow-up experiments we are using an experimental variation of probability distributions of antecedent and consequent terms (c.f. Oberauer & Wilhelm, in press) to investigate the impact of the conditional probability on belief in conditionals and conditional reasoning.

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