

Syntactic and Causal Constraints on the Necessity of Conditional Inferences by Readers

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Abstract

The data of three experiments (Campion, in press) confirm that the readers of texts including conditional arguments process the conditional syntax as an asymmetric constraint which warrants the Modus Ponens, a logically valid inference. However, causal knowledge can raise doubt about that inference and warrant the validity of the reciprocal inference (Affirmation of the Consequent). Thus, according to the theory of natural logic, the readers can make formal deductions, such as the modus Ponens. However, the readers also reason on causal bases and a formal deduction must not contradict knowledge about causality in the world. This provides further evidence that readers can represent their inferences as hypotheses (Campion, 2004).

Logically valid deductions are made during text comprehension (Campion, 2004; Rader and Sloutsky, 2002; Lea, O'Brien, Fisch, Braine and Noveck, 1990; Lea, 1995). What is controversial is whether these inferences reflect the readers' ability to draw formal deductions from text propositions. According to the mental or natural logic theory (Braine, 1978; Braine & O'Brien, 1991), the adults possess a set of mental rules that correspond to inference schemas and lead to make logically correct deductions. According to Rader and Sloutsky (2002), the mental model theory (Johnson-Laird, 1983. Johnson-Laird et Byrne, 2002) gives a better account of the deductions made when reading conditional arguments in texts. In support of that view, they used short stories with a conditional premise of the form: if antecedent then consequent (e.g., "If it is night, then it is cold outside"). A subsequent premise either affirmed the antecedent (e.g., "it is night"), and therefore elicited a Modus Ponens (MP) inference (e.g., "it is cold outside"), or affirmed the consequent (e.g., "it is cold outside"), and therefore elicited an affirmation of the consequent (AC) inference (e.g., "it is night").

AC inferences do not correspond to logically-valid deductions. However, Rader & Sloutsky (2002) found that the AC and MP inferences were both activated by the readers of their texts and were then both recognized with a same frequency as paraphrases of the text information. As pointed out by Rader & Sloutsky, these findings do not support the natural logic theory because no inference schema corresponds to AC inferences in the theory, in contrast to MP inferences that should be favored. In contrast, the findings support the mental model theory which stipulates that only one model is normally constructed to represent the meaning of a conditional premise. Building more models would be made when the

conditional meanings need to be exhaustively represented, and reading a text for comprehension does not require these additional models. Consequently, readers would not build the additional model that falsifies the AC inferences, and the AC and MP inferences of readers would be represented as identical.

The first aim of this study was to investigate whether readers represent their AC inferences as hypothetical facts, and therefore distinguish them from their MP inferences, that they represent as facts that are certain. A previous study (Campion, 2004) supported a similar claim: the readers would represent their deductions from categorical syllogisms as facts that are certain, while they represent the predictions they make about what should happen next in the story as hypotheses.

In agreement with that view, I suggest that AC inferences might be hypothetical inferences. Readers would draw the AC inferences, because they are the relevant conclusions of AC arguments, but would represent them as hypotheses, because they are not constrained by the conditional syntax. A complementary assumption is that the readers would represent the MP inferences as certain facts, because they are syntactically constrained by the text.

This study also examined the impact of readers' world-knowledge on the AC and MP inferences that involve causal relations between events. The existence of that impact has already been demonstrated in studies of reasoning. Thus, alternative causes prevent certainty responses to AC inferences from a causal conditional: "If cause then effect". For example, the conditional premise: "If a dog has a skin disease, then it will scratch constantly", leads to few certainty responses to AC inferences, presumably because the alternative cause "a dog has fleas" can be easily retrieved from knowledge about dogs. (Barrouillet, Markovits and Quinn, 2001; Cummins, 1995; Markovits and Quinn, 2002).

Similarly, reading conditional arguments would automatically activate the corresponding causal knowledge in readers Long-term memory (Campion & Rossi, 2001; Kintsch, 1998) and should invite the readers to check the compatibility of the conditional meaning with the underlying causal knowledge about the events in conditional relation (Singer, Halldorson, Lear, Andrusiak, 1992; van den Broek, 1990). However, if we assume that the conditional syntax constrains the making of MP inferences that are certain, world-knowledge should have a limited impact on the representation of MP inferences by readers. In contrast, AC inferences are not syntactically constrained, and their hypothetical or certain status will be heavily dependent on world-knowledge.

Table 1. Example of Conditional Arguments and Probes (between asterisks) used for a Story in the three Experiments.

STORY OUTLINE. *Little Claude was attending a course at a pony club.(...) That particular afternoon, Claude was riding Caramel, a light brown pony.*

EXPERIMENT 1.

FORWARD CONDITIONAL - MP INFERENCE. *If a pony has just been badly stung by an insect, it rears several times. Coming round a bend, Caramel had just been badly stung by an insect.*

** (Perhaps) Caramel reared several times **

FORWARD CONDITIONAL - AC INFERENCE. *If a pony has just been badly stung by an insect, it rears several times. Coming round a bend, Caramel reared several times.*

** (Perhaps) Caramel had just been badly stung by an insect **

EXPERIMENT 2.

REVERSE CONDITIONAL - MP INFERENCE. *If a pony rears several times, then it has just been badly stung by an insect.. Coming round a bend, Caramel reared several times*

** (Perhaps) Caramel had just been badly stung by an insect **

REVERSE CONDITIONAL - AC INFERENCE. *If a pony rears several times, then it has just been badly stung by an insect. Coming round a bend, Caramel had just been badly stung by an insect.*

** (Perhaps) Caramel reared several times **

EXPERIMENT 3.

[.Same story, but Caramel is described as nervous]

REVERSE CONDITIONAL - MP INFERENCE. *If a nervous pony stays calm, then its rider has talked to it all the time.*

+ A + B

FORWARD CONDITIONAL - AC INFERENCE. *If a horse rider has talked to a nervous pony all the time, then the pony has remained calm.* + A + B

A = *Claude went for a long ride on Caramel and the pony remained calm.*

B = ** (Perhaps) Claude talked to Caramel all the time **

The Two Sets of Conditionals

Two set of twenty-four cause-effect pairs were selected. In the first set, the causes were strongly sufficient but weakly necessary for the effects, whereas they were only moderately necessary and sufficient for the effects in the second set. Forward and reverse conditionals were written by placing the cause of each pair in the antecedent or consequent position. (see Table 1). Twelve judges evaluated the truth frequency of the forward and reverse conditionals on a 8-point scale with the value 1 corresponding to "never true". For the first set of conditionals, the truth frequencies were much higher for the premises in the forward direction (6.4) than the premises in the reverse direction (5.2),

whereas for the second set of conditionals, the truth frequencies recorded for the premises in the forward direction were not so different from those recorded in the reverse direction (4.8 vs 5.2). The corresponding interaction was significant ($F(1, 11) = 43.28$, $MSE = .0141$, $p < .001$; $F(1, 46) = 28.61$, $MSE = 0.419$, $p < .001$)

Experiment 1

The aim of this experiment was to establish that readers do not confuse their representation of AC and MP inferences when both the conditional syntax and their world-knowledge constrain the MP inference direction. The text should represent the AC inference as hypothetical, whereas the MP inferences should be represented as certain. The conditional premises were therefore written in the forward direction, and the involved causes were strongly sufficient and weakly necessary for the effects. For example, "If someone drinks too much coffee before going to bed, then he doesn't sleep".

Method

Participants. The participants were 32 students from the University of Paris X who had not studied logic. They took part in the experiment on a voluntarily basis.

Materials. The twenty-four experimental texts were short narratives, and their last two sentences expressed a conditional argument in the AC or MP form (see Table 1). The first sentences in the arguments were the conditionals written in the forward direction, with a strongly sufficient and weakly necessary cause, as established in the former control study. Care was taken that the truth of the conditional inferences only depend on the argument form and world-knowledge, but was independent from the other story events. The entire texts consisted of about 80 words in 4 to 7 sentences. There were also eight filler texts.

Twenty-four judgment probes expressed the events to be inferred. A hypothetical version of these probes was created by adding the adverb "peut-être", a French word meaning "maybe". Each of these probes was followed by a second filler probe, which also involved text information, but was unrelated to the inference and could call for the answer "false". Otherwise, the eight filler texts were followed by two filler probes, the first of which was always false. Finally, the participants were expected to answer "false" to 47% of the probes.

Procedure. The participants worked individually in a session that lasted approximately 30 minutes. The texts were read sentence by sentence from the middle of a computer screen. When they had read a text sentence, the participants pressed the space bar and it was replaced by the next sentence. When the last text sentence had disappeared from the screen, a row of asterisks was displayed for 500 ms in the middle of the screen and was then replaced by the first probe, which was displayed with asterisks on each side of it. The second probe was presented in the same way. The participants were instructed to press the "true" key when the information expressed in the probe was true according to the text and to press the "false" key otherwise. The "True/False"

keys were the "a" or "p" keys (the first and last letters on the top line of letters on a French "azerty keyboard), with the "true" key corresponding to the preferred hand of the participants. The signal "new text" then appeared on the

Table 2. Acceptance Percentages and Latencies (ms) of Probes (Experiment 1 – Forward conditionals)

	Probe Type	
	Affirmative	Hypothetical
AC Inference		
Latency	3208	2923
Percentage	69%	89%
MP Inference		
Latency	2556	2800
Percentage	86%	94%

screen, and a press on the space bar was required to bring up the new text. The participants were told that their response times were being recorded, and were asked to answer quickly. No feedback was given to the participants about their answers. The participants underwent a training phase before they began the experiment proper. A training text and two probes were presented following the same procedure as for the rest of the experiment. The participants were then trained quickly to select the "True/False" keys. The words "Vrai" (true) and "Faux" (false) were successively presented in the middle of the screen, in a random order, and the participants answered with the appropriate keys. Fourteen responses were required during the training phase, and any errors were pointed out by an appropriate message.

Results and Discussion

Acceptance rates. The mean rate of the errors made by the participants in response to the filler probes (i.e., the second probe following the experimental texts, and the two probes that followed the filler texts) was 13.3% (SE = 0.46), which attested that the stories were being read attentively. The acceptance percentages of the inference probes are shown in Table 2. They provided a first indication that the readers discriminated between the MP and AC inferences they drew from the texts. The percentage of affirmative probes accepted as true was significantly higher for MP inferences (89%) than for AC inferences (69%). ($F(1, 31) = 10.92$, $MSE = .0396$, $p < .01$; $F(1, 23) = 11.66$, $MSE = .0268$, $p < .01$).

Acceptance latencies. The acceptance latencies of the inference probes are shown in Table 2. A two-factor analysis of variance (ANOVA) with repeated measures indicated that inference types had an effect ($F(1, 31) = 43.08$, $MSE = 111920$, $p < .01$; $F(1, 23) = 33.73$, $MSE = 3616576$, $p < .01$), that the probe type had no significant effect ($p > .7$), and that there was a significant interaction between these factors ($F(1, 31) = 6.59$, $MSE = 339666$, $p <$

$.05$; $F(1, 23) = 7.98$, $MSE = 210497$, $p < .01$). Planned comparisons indicated that the affirmative probes were more rapidly accepted as true than the hypothetical ones for MP inferences ($F(1, 31) = 4.85$, $MSE = 195782$, $p < .05$; $F(1, 23) = 4.14$, $MSE = 172223$, $p < .054$), whereas the opposite

Table 3. Acceptance Percentages and Latencies (ms) of Probes (Experiment 2 – Reverse conditionals)

	Probe Type	
	Affirmative	Hypothetical
AC Inference		
Latency	2388	2650
Percentage	82%	96%
MP Inference		
Latency	2543	2576
Percentage	73%	93%

effect was significant for AC inferences ($F(1, 31) = 4.2$, $MSE = 310202$, $p < .05$; $F(1, 23) = 4.23$, $MSE = 230712$, $p < .052$).

According to these findings, the readers' representations of MP inferences were closer in meaning to the affirmative probes than to the hypothetical probes. The reverse was true for the readers' representation of AC inferences. Thus, the readers discriminated between the AC and MP inferences: they represented the AC inferences as being hypothetical, and the MP inferences as being certain.

Experiment 2

The results of Experiment 1 do not make it possible to distinguish between the respective roles of the conditional syntax and world knowledge in constraining inference representations. The aim of this experiment was to find out whether the presence of a strongly sufficient and weakly necessary cause would lead the reader to be more confident about their world-knowledge than about the conditional syntax. Thus, the conditionals used in Experiment 1 were presented in the reverse direction: "If effect then cause". This reversion should have a limited impact if the processes involved in AC and MP inferences are determined predominantly by the conditional syntax.

Method

Participants. The participants were 32 students from the University of Paris X who had not studied logic. They took part in the experiment on a voluntary basis.

Materials, procedures and design. They were the same as those of Experiment 1, except that the major premises were written in the reverse order: "If effect, then cause". (see Table 1).

Results and Discussion

The mean of the participants errors in response to filler probes was 15.5% (SE = 0.42), which demonstrated that the stories were read attentively. The acceptance percentages and latencies of probes are shown in Table 3. No interesting effect could be found in the acceptance rates. For the acceptance latencies, a two-factor analysis of variance (ANOVA) with repeated measures indicated a significant main effect of probe type ($F(1, 31) = 4.74$, $MSE = 189025$, $p < .05$; $F(1, 23) = 4.06$, $MSE = 165801$, $p < .056$), no main effect of inference type ($p > .7$), but a trend for an interaction between the inference and probe types, although it was only near significant with items as the random variable ($F(1, 31) = 1.62$, $MSE = 358813$, $p < .22$; $F(1, 23) = 3.42$, $MSE = 127541$, $p < .08$).

In sum, these findings indicate that the AC inferences were represented as being closer in meaning to the certain probes than to the hypothetical probes. In contrast, the MP inferences were generally represented as being equally compatible in meaning to the certain or the hypothetical probes. Thus, in agreement with the hypothesis that AC inferences are knowledge-based, the present data indicated that when AC inferences involve the effect of a strongly sufficient cause, they are represented as certain facts. The present data also demonstrate that the readers' knowledge can cast doubt on the certainty of MP inferences, despite the conditional syntax. In this experiment, the MP inferences required the readers to conclude that a weakly necessary cause is true, and the readers were presumably able to assess this lack of necessity, possibly by retrieving some alternative causes that could produce the same effect.

Experiment 3

The aim of this experiment was to show that readers can represent MP inferences as necessary because they are constrained to do so by the conditional syntax. Therefore, the conditional premises were cause-effect pairs of moderate strength, the cause being neither strongly sufficient nor weakly necessary for the effect.

Method

Participants. The participants were 32 students from the University of Paris X who had not studied logic. They took part in the experiment on a voluntary basis. None of them successfully passed a Wason task, unlike three students who were replaced.

Material. The texts of this experiment were the same as those used in Experiments 1 and 2, except for the two last sentences, which were replaced by new conditional arguments (see Table 1). The new conditional premises expressed causally-related events and, as in the control study, the cause was of moderate strength. In comparison to the cause-effect pairs used in Experiment 1 and 2, the new cause-effect pairs could be considered to be more necessary and less sufficient for the effect. For the MP arguments, the new conditional premises were written in the reverse direction: "If effect then cause". Conversely, for the AC

arguments, the new conditionals were written in the forward direction: "If cause then effect". As a result of that reversal, the AC and MP inferences both involved inferring the same causes from the same effects. Therefore, whatever the impact of world-knowledge, it was presumably identical for

Table 4. Acceptance Percentages and Latencies (ms) of Probes (Experiment 3)

	Probe Type	
	Affirmative	Hypothetical
AC Inference - Forward		
Latency	2275	2251
Percentage	85%	96%
MP Inference - Reverse		
Latency	2068	2355
Percentage	89%	95%

both inference types. In particular, the same counter-examples could decrease the certainty of the AC and MP inferences. A new set of affirmative and hypothetical probes replaced those used in Experiments 1 and 2, and the filler probes remained unchanged.

Procedure. It was the same procedure as that used in Experiment 1, except that at the end of the entire experiment, each participant performed an unexpected Wason task.

Results and Discussion

The participants' mean error rate to the filler probes was 13.1% (SE = 0.6), which confirmed that the stories were being read attentively. The acceptance percentages and latencies of probes are shown in Table 4. The acceptance rates did not differ significantly across the experimental conditions. The acceptance latencies of the inference probes are reported in Table 4. A two-factor analysis of variance (ANOVA) with repeated measures indicated that inference had no main effect ($p > .3$), probe type had no significant effect ($p > .1$), but that there was a significant interaction between these factors ($F(1, 31) = 5.82$, $MSE = 133001$, $p < .022$; $F(1, 23) = 4.06$, $MSE = 142877$, $p < .056$). In agreement with predictions, the planned comparisons indicated that the affirmative probes were indeed more rapidly accepted as true than the hypothetical ones for MP inferences ($F(1, 31) = 8.47$, $MSE = 155305$, $p < .01$; $F(1, 23) = 11.19$, $MSE = 88215$, $p < .01$). For the AC inferences, the mean acceptance latencies for the affirmative and hypothetical probes were nearly equal.

According to these data, the MP inferences were closer in meaning to the affirmative probes than to the hypothetical ones, whereas the meaning of AC inferences was compatible with both the hypothetical and certain probes. These findings suggest that MP inferences were represented

as certain facts by readers, whereas the AC inferences were represented as hypotheses about the text.

In Experiment 3, causal knowledge could not be used to distinguish the conditional inferences, so it must have been the processing of the conditional syntax that constrained the readers to represent their MP inferences as certain. The data also confirm that, without the support of a conditional premise that syntactically warrants their validity, the certainty of AC inferences is entirely determined by the causal strength with which the conditional consequent allows the readers to conclude to the conditional consequent, according to their world-knowledge about the underlying events. In Experiment 3, the conditional consequent entailed the conditional antecedent as a cause that was not necessary but probable, and readers considered the AC inferences to be hypothetical.

General Discussion

This study first supports the conclusion that for readers who are not experts in logical processes, the conditional syntax acts as an asymmetric constraint, but they also consider their causal knowledge about the conditional events. In addition, the syntactic and causal characteristics of the conditional arguments were shown to result in AC and MP inferences that varied depending on the certain or hypothetical status of their representations. Therefore, whereas a previous study had demonstrated that AC and MP inferences were drawn during reading (Rader & Sloutsky, 2002), the present study indicates that these inferences will not be systematically identical in the readers' representation of the situation described in the text.

Taken together, the results of these experiments support the conclusion that both the conditional syntax and the readers' causal knowledge determine the conditional inferences made by readers. Processing the conditional syntax instructs the readers about the logical legacy of MP inferences, whereas the sentence comprehension involves associative processes, and makes it possible to retrieve causal knowledge about the events in a conditional relationship. The strength of the causal relations involved would be evaluated, as for any pair of text events (Singer, Hallordson & Andrusiak, 1992; van den Broek, 1990). That causal evaluation would be a automatic process when the activated knowledge match the causal relation implied by the text events. The outcome would be the acceptance or rejection of the conditional instruction as warranting the MP inferences. Thus, MP inferences would be always conceived as syntactically constrained, but they would be only represented as certain if the underlying knowledge remains compatible with the syntactic instruction provided by the conditional premise. In the case of AC inferences, the mention of the conditional consequent in the minor premise would invite the readers to infer the conditional antecedent. However, since these inferences are not syntactically constrained, their representation as certain or hypothetical would depend purely on the assessment of the strength of the underlying causal relations. The impact of causal

knowledge on the processing of AC inferences would therefore be central and exclusive, in contrast with the situation for MP inferences, where the conditional syntax intervenes.

With regard to the impact of causal knowledge on MP inferences, it is important to note that, according to the findings of Experiment 3, the weakness of the same causal relationship was not sufficient to prevent the drawing of certain MP inferences, although it did prevent the certainty of AC inferences. This finding clearly suggests that the conditional syntax constrains the MP inferences and take precedence over the readers causal knowledge. The results of experiment 2 do not contradict that finding but show that there is generally a limit to readers' loyalty to the conditional syntax. Accordingly, when their causal knowledge clearly contradict the conditional relations, making the MP inferences rather absurd, the readers are finally uncertain about their MP inferences, and represent them as hypotheses.

The contribution of the conditional syntax to conditional inferences by readers has implications for applying theories of conditional reasoning to text comprehension. A mental model account of the syntactic discrimination that, without contradicting knowledge, readers operate between the certainty of MP and the hypothetical nature of AC inferences is not possible with a single mental model, even if the model is considered hypothetical. According to Johnson-Laird (2002), individuals normally represent the conditional "If A then B" with a single model plus three dots:

A B
...

The three dots account for the fact that the individuals keep in mind that possibilities other than the simultaneous truth of A and B are implied by the conditional, even if these possibilities are as yet being ignored. Thus, the three dots can be viewed as the kind of hypothetical tag that, I propose, characterizes hypothetical inferences. Consequently for the mental model theory, if the individuals are then shown proposition B, they will infer the conclusion: A, but it will be tagged as hypothetical because of the three dots. The issue is, however, that the same consideration prevails for MP inferences. If the individuals are presented with proposition A instead of proposition B, then they will infer proposition B, and it too will be tagged as hypothetical, because of the three dots. Therefore, the only way that seems to allow us to provide a mental model account of hypothetical AC inferences and certain MP inferences would be to consider that the individuals represent the two following models from the conditional statement:

A B
Not A B
...

In sum, a mental model account of the drawing of hypothetical AC inferences and certain MP inferences implies that readers build an additional model that

represents the falsity of the conditional antecedent in conjunction with the truth of the consequent. In theory, this “fleshing out” process is supposed to demand effort (Johnson-Laird & Byrne, 2002), and, according to Rader & Sloutsky (2002), it is not compatible with text comprehension requirements. One way of reconciling the theory with our findings would be to suggest that alternative models may only be represented when the conditionals involve a causally-related event in familiar situations, or to introduce a syntactic direction in mental models (from the antecedent to the consequent).

The data collected for MP inferences, especially those of Experiment 3, support the natural logic theory. According to that theory, when a conditional of the form: “If A then B” is encountered, it is interpreted as an explicit instruction to infer B given A, the truth of B being warranted given A. (Braine, 1978). The data collected in Experiment 3 support this theoretical assumption. Accordingly, even when the MP inference consisted in inferring a cause from its effect, and presumably evoked some alternative causes, the MP inferences were still represented as certain by readers. Otherwise, by showing that readers easily draw MP inferences and represent them as necessary entailed, the data are compatible with the natural logic assumption that the necessary truth of MP inferences is inherent to applying a deductive schema.

It is worth noticing that this study also demonstrated a limit to the readers’ loyalty to formal logic. The results of Experiment 2 indicate that the readers may not follow the syntactic instruction of conditional premises, and may not represent their MP inferences as certain. When the readers’ causal knowledge does not support the validity of the inference, and therefore prohibits a content-free usage of the conditional syntax, the readers represent their MP inferences as hypothetical. A possible explanation of the data collected in Experiment 2 is that the readers experience cognitive difficulties in activating a representation of the asymmetrical meaning of a conditional, when it is the reversed meaning that is strongly compatible with the causal knowledge. Thus, in Experiment 2, the readers rapidly confuse the exact conditional meaning with the more appropriate meaning that they know and corresponds to the reversed premise. Note that this account corresponds to the observed effects, because it is a reversed interpretation of the conditional, rather than a biconditional interpretation.

Finally, this study confirms that the readers represent inferences that are unwarranted both by the text and by their knowledge as hypotheses that are distinct from their representations of necessary and certain inferences (Campion, 2004). It also indicates that readers process the conditional syntax in order to consider the deductions of the MP form as necessary, but only do so when the conditionals receive at least a partial support from their causal knowledge.

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