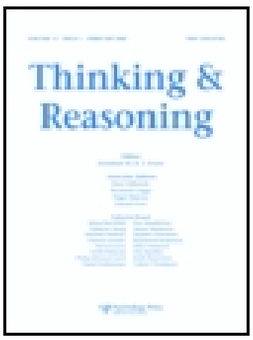

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Abstract reasoning and the interpretation of basic conditionals

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ABSTRACT

Studies examining the interpretation that is given to if–then statementstypically use what are referred to as basic conditionals, which give contextless relations between two unrelated concrete terms (If the ball is blue, then the shape is square). However, there is some evidence that basic conditionals require a more abstract form of representation. In order to examine this, we presented participants with truth-table tasks involving either basic conditionals or conditionals referring to imaginary categories (If it is a bori, then it has red wings), and standard conditional inference tasks with abstract and familiar premises. As expected, fewer typical defective conditional interpretations were given to basic conditionals. In addition, partial correlations showed a unique relationship between the interpretation of basic conditionals and abstract inferential reasoning. Results suggest that people process basic conditionals as a form of abstract reasoning, and that the interpretation of conditionals must consider the semantic context.

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KEYWORDS Conditional reasoning; interpretation; basic conditionals; abstract reasoning

Understanding the nature of reasoning is one of the major questions in human cognition. Within this broader context, understanding how people reason with conditional statements is one of the most intensively studied questions. Conditionals refer to if–then statements. Such statements are encountered in most domains of human activity, and are used to express a variety of different meanings. Young children use if–then statements at a very early age (Scholnick & Wing, 1991). Conditionals can be used to express any number of pragmatic relations, such as promises and threats (Evans & Twyman-Musgrove, 1998; Fillenbaum, 1975; Wing & Scholnick, 1981), although they can also be used to express hypothetical relationships and are used to express hypotheses or postulates in both mathematical and scientific reasoning.

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One of the more important underlying questions concerns how conditionals are interpreted. There are several levels at which this question can be approached. For example, there is an ongoing debate that concerns the nature of people's understanding of simple conditional statements. Probabilistic approaches to reasoning suggest that people understand if–then statements as indicative of a very likely relation between antecedent and consequent terms (Evans, Over, & Handley, 2003; Oaksford & Chater, 2007). Theories such as rules-based theories (Braine, 1978) or mental model theory (Johnson-Laird & Byrne, 1991), in contrast, suppose that if–then statements that are not explicitly probabilistic will be processed as indicating the certainty of the underlying relation (see Goodwin, 2014). While this debate is an important one, there is a more basic question which concerns the structure underlying the semantics of conditionals. This is determined by the patterns of statements concerning the antecedent and consequent that are considered to be true if the conditional statement is accepted as true. Note that we can replace "true" with "very probable" without altering this basic description. The key question with respect to the underlying structure is whether there is a basic underlying semantics of the if–then connective, or whether this is modulated by content or context. This question is complicated by the existence of very clear pragmatic effects, which show clear differences in the interpretation of different forms of conditionals, including conditional promises and threats (Fillenbaum, 1975; Newstead, 1997). Similarly, obligations and permissions also have clear effects on conditional inferences (Cheng, Holyoak, Nisbett, & Oliver, 1986). In order to eliminate possible effects due to pragmatic considerations, much of the research examining the basic interpretation of conditionals has used what are known as *basic conditionals*. These are conditionals which have concrete referents for both antecedent and consequent terms, but with no clear relation between them, e.g., if something is blue, then it is round. Studies examining the interpretation of basic conditionals have led to one important controversy, but have left another key question unanswered.

One of the most frequent ways of examining the interpretation of conditionals is the truth-table task. In this, people are given a conditional statement followed by the four combinations consisting of true or false antecedent and consequent terms. For each combination, they are asked whether this indicates that the conditional rule is true, false or is indeterminate. A material conditional interpretation of if–then statements would imply that people should consider the three combinations of antecedent and consequent terms that are "true" in the truth-table representation of conditionals (P & Q; not-P & Q; not-P & not-Q) as indicating that the conditional rule is true, while the P & not-Q term should be considered to indicate that the rule is false. However, many studies that have used truth-table tasks have found that one of the most frequent response patterns is what has been referred to as the defective

conditional (see Evans & Over, 2004, for a review). A defective conditional response occurs when the P & not-Q combination is judged as making the conditional false, the P & Q combination is judged as making the conditional true, while the other two combinations (not-P & Q, not-P & not-Q) are judged to be indeterminate.

The presence of such a defective pattern has been a matter of debate within the context of theories that consider that the underlying interpretation of conditionals must be analogous to the material conditional representation of the conditional, such as mental model theory, or theories that consider reasoning to be an essentially probabilistic process (Over & Baratgin, 2016; Politzer, Over, & Baratgin, 2010). However, it is also important to consider that defective conditional interpretations only characterise conditionals that do not allow for a pragmatic interpretation (Barrouillet, Gauffroy, & Lecas, 2008; Gauffroy & Barrouillet, 2009; Newstead, 1997).

Although the underlying interpretation of defective conditionals remains a matter of debate, it does seem clear that, in the absence of a specific pragmatic context, people's prime interpretation of basic conditionals is the defective conditional. However, while the question of the status of defective conditionals is of key importance, there is another fundamental question that is elided by the choice to use basic conditionals in most truth-table like tasks. This is the question of whether the interpretations that people make of *basic conditionals* reliably access the basic interpretation of conditionals. To be clear, this supposes that when faced with a meaningless if–then relation, even one that is anchored by familiar antecedent and consequent terms, people will reliably activate the relevant semantics. However, there is no real evidence for this assumption. In fact, Douven, Elqayam, Singmann, and van Wijnbergen-Huitink (2017) have proposed that having an inferential connection between antecedent and consequent terms is an important component in the way that conditionals are evaluated (see also Barrouillet & Lecas, 1998 for an earlier version of this hypothesis). In this context, basic conditionals which do not have any such connection between the terms would be much more difficult to process.

In fact, a recent study that has examined Barrouillet's developmental theory (Barrouillet & Lecas, 1999; Barrouillet et al., 2008; Gauffroy & Barrouillet, 2009) suggests that processing decontextualised basic conditionals might represent a more abstract form of representation than conditionals with inferential connections (Markovits, Brisson, & de Chantal, 2016). Barrouillet's theory suggests that children's interpretations of conditionals is strongly determined by working memory capacity, implying that in the absence of a clear pragmatic interpretation, young children should not be able to generate the typical defective conditional interpretation found with adults. This has in fact been found when the interpretation of basic conditionals is examined (Barrouillet & Lecas, 1999). However, Markovits et al. (2016) hypothesised that

basic conditionals, even though both the antecedent and consequent terms have familiar concrete referents, actually require some form of abstract representation. In order to examine this, they presented young children with truth-table tasks using two types of conditionals. Half were standard basic conditionals, while the other half were conditionals with content referring to imaginary creatures (which we refer to as imaginary categorical premises), but where the if–then relation could be interpreted as an underlying class–property relation (e.g., If an animal is a bori, then it has red wings). Although the interpretation of basic conditionals was consistent with previous results, with very low levels of defective conditional interpretations, as hypothesised, children produced much higher levels of defective conditionals on imaginary categorical conditionals than on basic conditionals.

The aim of the present study is to extend this analysis to adults. We first attempted to replicate the result that the levels of defective conditional interpretations would be greater with imaginary categorical conditionals than with basic conditionals in the standard truth-table task with adults. Second, we examined the relationship between the nature of the interpretation of these conditionals and inferential reasoning, something that to our knowledge has not been previously looked at. In order to do this, we presented participants with standard conditional inference problems in addition to truth-table problems. These present the four basic inferences that characterise conditional reasoning. The most basic of these is the Modus Ponens inference (MP: P implies Q, P is true, therefore Q is true), which requires a base level of acceptance of the if–then relation. The three other inferences are the Affirmation of the Consequent inference (AC: P implies Q, Q is true, no valid conclusion), the Denial of the Antecedent inference (DA: P implies Q, P is false, no valid conclusion) and the Modus Tollens inference (MT: P implies Q, Q is false, therefore P is false).

Now, for the conditional inferences, our basic measure is the extent to which people give the "logical" response to the four inferences, that is accepting the invited conclusion for the MP and MT inferences and rejecting any conclusion for the AC and the DA inferences (with a minor variation which will be explained later). We assume, in line with many developmental studies, that such responses require an underlying complete representation of the conditional. Now, while the defective response pattern to the truth-table task is somewhat controversial, it is clear that this is the preferred representation of most adults. In addition, Barrouillet's developmental studies clearly show that the defective conditional pattern is developmentally more advanced than other forms of interpretation, such as conjunctive and biconditional. Thus, we suppose that the defective conditional interpretation does indeed correspond to the basic interpretation of the conditional, and should be required in order to give the logical response to the four conditional inferences. Thus, our overall hypothesis is that there should be a positive

relationship between the level of production of defective conditionals and the level of "logical" responses produced with the inferential problems. In addition, we can be more specific. The results of Markovits et al. (2016) suggest that basic conditionals require a form of abstract representation. This in turn suggests that the interpretation of basic conditionals accessed by the truth-table task corresponds to the interpretation required to reason logically with abstract content. We thus hypothesised that the level of logical responding to abstract conditional inferences will be more strongly related to the level of production of defective conditional interpretations on the truth-table task with basic conditionals than the level of production of defective conditional interpretations on the truth-table task with imaginary categorical conditionals.

In order to examine this latter hypothesis, we use two types of premise for the inferential problems. The first is fully abstract premises. The second is premises with familiar categorical content. These were chosen to have familiar content for which the relationship between the terms was categorical. In addition, these were chosen to produce relatively low levels of logical responding compared to familiar premises with very easily accessible alternative antecedents (taken from Markovits, 2000). This was done in order to ensure that reasoning with the familiar premises required some cognitive effort, making the comparison between contents clearer.

Method

Participants

A total of 116 participants (42 men; 74 women: average age = 21 years 2 months) were recruited. All participants were students at a Montreal university and were volunteers.

Materials

Eight paper and pencil booklets were prepared. Each one was composed of four parts given in different orders.

Conditional inferences with familiar categories

There were two sets of conditional inferences. The first presented the instruction to "Suppose that the following rule is true" followed by the major premise: "If a plant is a cactus, then it will have thorns".

Directly following this, four inferences were presented on a single page, defined by the acceptance or the negation of the antecedent and consequent terms of the major premise. The first such inference was presented in the following manner:

A plant is not a cactus. One can conclude that:

1. The plant has thorns.
2. The plant does not have thorns.
3. One cannot conclude if the plant has thorns or not.

Following this, three more inferences were presented with the same format of responses. These were:

A plant does not have thorns.
A plant is a cactus.
A plant has thorns.

On the second page, the rule "If an object is a knife, then it has a blade" was presented, along with the four inferences (in a different order).

Conditional inferences with abstract content

The format of these was identical to that used in conditional inferences with familiar categories, except that the two rules used completely abstract terms. These were:

If there is a flop, then there is a mauchard.
If there is a zurde, then there is a triffart.

Truth-table task with basic conditionals

Before the presentation of any of the truth-table tasks, participants were given the following instructions:

> In the following pages, you will be presented with different rules. Some of these rules contain strange words. These words were invented for this exercise. For each of the rules, you will be presented with different situations. For each of these, you must indicate whether the situation shows that the rule is true, or that the rule is false, or whether it does not show that the rule is true or false. Indicate **true** if the situation shows that the rule is true, **false** if the situation shows that the rule is false, or **one cannot know** if the situation does not allow knowing if the rule is true or false.

Following this, the two if–then rules using basic conditionals were presented, with each rule on the top of a new page. These were taken from Markovits et al. (2016) and consisted of basic conditionals identical to those used by Barrouillet and Lecas (1999):

If a circle is red, then the star is black.
If Melinda wears a red sweater, then she will wear green pants.

Below each rule, four specific cases were presented (corresponding to all combinations of affirming or negating either the antecedent or consequent terms). Three choices were given for each combination. For example, following the rule "If a circle is red, then the star is black", the following statement, combining a false antecedent and a true consequent, was presented, with the three options directly following it:

1. A circle is green and the star is black.

   This statement shows that the rule is:

   1. True
   2. One cannot know
   3. False

The three other statements were:

1. A circle is red and the star is black.
2. A circle is red and the star is white.
3. A circle is blue and the star is green.

The four specific cases corresponding to all combinations of affirming or negating either the antecedent or consequent terms were presented, with the order varied for each rule.

Truth-table task with imaginary categorical conditionals

The format of these was identical, except that the rules that were presented referred to imaginary categories. These were:

If a plant is a mandola, then it has blue leaves.
If an animal is a bori, then it has red wings.

Design

The eight booklets presented all of these tasks, but were constructed in the following way. The first four booklets presented the conditional inferences first, followed by the truth-table tasks. In these, the order of the conditional inferences and the truth-table tasks were systematically varied by block in the following way:

Version 1: Conditional inferences (Abstract + Familiar categories) + Truth-table task (Basic conditionals + Imaginary categorical conditionals)

Version 2: Conditional inferences (Familiar categories + Abstract) + Truth-table task (Basic conditionals + Imaginary categorical conditionals)
Version 3: Conditional inferences (Abstract + Familiar categories) + Truth-table task (Imaginary categorical conditionals + Basic conditionals)
Version 4: Conditional inferences (Familiar categories + Abstract) + Truth-table task (Imaginary categorical conditionals + Basic conditionals)

The final four versions were identical to these, except that the truth-table tasks were presented first, followed by the conditional inferences.

Procedure

Booklets were given to students individually in the school library. Participants were told to take as much time as needed to respond.

Results

We first analysed performance on the truth-table tasks. Analysis of responses indicated that there were three major interpretations that were generated. As has been often observed, the most frequent pattern of responses corresponded to the defective conditional, followed by defective biconditional (P & Q is true; P & not-Q is false; not-P & Q is false; not-P & not-Q is irrelevant) and conjunctive (P & Q is true; all other combinations are false) patterns. Table 1 shows the relative frequency of each of these categories of response for the basic and imaginary categorical conditionals. Inspection of this table indicates that the distribution of responses differed by premise type.

We then specifically examined the rate of production of the defective conditional. In order to do this, we simply added up the number of defective conditional interpretations for the two problems with the same premise type. We performed an ANOVA with number of defective conditional interpretations as dependent variable with premise type (Imaginary categorical, Basic) as a repeated measure and problem order, truth-table premise order and inference premise order as between subjects' variables. This gave only a main effect of premise type, $F(7,108) = 14.79$, $p < 0.001$. Mean number of defective conditional interpretations was greater for the imaginary categorical conditionals ($M = 1.04$, SD = 0.94) than for the basic conditionals ($M = 0.78$,

Table 1. Percentage of defective conditional, defective biconditional and conjunctive interpretations for basic and imaginary categorical conditionals.

Interpretation	Basic conditionals	Imaginary categorical conditionals
Defective conditional	39.2	52.2
Defective biconditional	20.3	15.1
Conjunctive	18.5	8.3
Other	22.0	24.1

SD = 0.93). As can be seen from the table, the increase in defective conditional interpretations was associated with relative decreases in defective biconditional and conjunctive interpretations, although these were not individually significant.

We then analysed performance on the inferential tasks. There is one problem with simply adding up correct answers to the four inferences. In some cases, people reject the basic if–then relation, which involves rejecting the MP inference also. However, such a response is often followed by rejection of the other inferences, which in the case of the AC and DA inferences is the logically correct response. In order to discount this possibility, we constructed a logical reasoning score in the following way. For each premise, if the MP inference was not accepted, the logical reasoning score was 0, otherwise the logical reasoning score was the sum of the correct responses to the AC, DA, and MT forms. This gave a score varying between 0 and 6 for the two abstract premises and for the two familiar premises used in the inferential problems. It should be noted that the overall acceptance rate for the MP inferences was 93.7% when the inferential problems were presented first, and 96.7% otherwise. The results of the statistical analyses were identical even when MP performance was included in the reasoning score. We then performed an ANOVA with logical reasoning score as dependent variable, with premise type (Abstract, Familiar) as a repeated measure and problem order, truth-table order and inference order as between subjects' variables. This gave a main effect of premise type, $F(7,110) = 64.60$, $p < 0.001$, and problem order, $F(1,110) = 9.45$, $p < 0.01$. As expected, logical reasoning scores were higher for the familiar premises ($M = 3.99$, SD = 1.67) than for the abstract premises ($M = 2.82$, SD = 1.67). Participants who were given the truth-table tasks initially performed better than those who received the inferential problems first for both the familiar premises (Truth-table first: $M = 4.35$, SD = 1.66; Inference first: $M = 3.69$, SD = 1.63) and the abstract premises (Truth-table first: $M = 3.33$, SD = 1.77; Inference first: $M = 2.38$, SD = 1.45). We also replicated this analysis using logical form as a second repeated measure. This gave the same pattern of results.

We then examined the relationship between the production of defective conditionals on the truth-table tasks and logical reasoning scores (see Table 2). As hypothesised, this showed strong correlations between these two measures for both contents. In addition, consistent with our second hypothesis, the correlation between reasoning with abstract premises and performance on the truth-table task with basic conditionals is higher than the correlation between reasoning with abstract premises and the truth-table task with imaginary categorical conditionals, $z = 1.62$, $p = 0.05$ (one-tailed). Nonetheless, there are strong correlations between the two measures of reasoning performance and the two measures of truth-table performance. In order to disentangle these effects, we calculated correlations between truth-table

Table 2. Correlations between defective conditional responses on truth-table tasks and logical reasoning scores.

	Logical reasoning – abstract	Truth-table – basic	Truth-table – imaginary
Logical reasoning – Familiar	0.55**	0.39**	0.41**
Logical reasoning – Abstract		0.37**	0.26**
Truth-table – Basic			0.69**

**$p < 0.01$.

performance with the imaginary categorical and the basic premises and logical reasoning scores with abstract and familiar premises, partialling out the contribution of the other tasks. This gave a pattern that is also consistent with our second hypothesis (see Table 3). There was a marginally significant positive partial correlation between number of defective conditional interpretations with basic conditionals and logical reasoning score with abstract premises, with no correlation between the latter and numbers of defective conditional interpretations with imaginary categorical conditionals, with the difference between them being significant, $z = 2.60$, $p < 0.01$ (one-tailed). The opposite pattern was observed with inferential performance on the familiar premises.

Discussion

The general results on both the truth-table and the inference tasks are consistent with what has been found in previous studies. The response patterns found on the truth-table task show that, consistent with previous results, the most common pattern corresponds to the defective conditional, with defective biconditional and conjunctive patterns being produced at a lower level. It should be noted that, as with the study examining truth-table performance among pre-adolescent children, the most commonly observed interpretation of both forms of conditionals was the defective conditional. The fact that the pattern of responses was very similar for both forms of premise reduces the possibility that people were using some form of pragmatic interpretation for either conditionals. This in turn suggests that both forms of conditional activated the same basic representation. Performance on the inference tasks

Table 3. Partial correlations between truth table and inferential performance.

	Defective conditional responses on truth-table task	
Logical reasoning scores	Basic	Imaginary categorical
Familiar premises	−0.02	0.28**
Abstract premises	0.19*	−0.15

*$p < 0.10$; **$p < 0.05$.

shows that there is a higher rate of logically correct responding with familiar categorical premises than with abstract premises, which is also consistent with previous results (Markovits & Vachon, 1990).

Analysis of the interactions among these various elements allow three specific conclusions. First, they show that adults produce higher levels of defective conditional patterns to the truth-table task when given meaningless terms with a meaningful relation than when given meaningful, concrete terms without a meaningful relation between the elements. Again, these results replicate those found with pre-adolescents (Markovits et al., 2016). Second, they show a clear order effect. People doing the truth-table task initially produce higher levels of conditional responding, while performance on the latter is not affected by order. To our knowledge, this is the first result of this kind. Finally, the relationship between performance on truth-table tasks and inferential performance shows a pattern that is consistent with the idea that basic conditionals are more "abstract" than the imaginary categorical premises used here.

Behind the use of so-called basic conditionals as a relatively pure measure of how people interpret conditionals is the idea that people possess a relatively abstract semantics of if–then relations. Thus, using concrete terms with a meaningless if–then relation would be a natural way to examine this interpretation. However, the present results clearly suggest something quite different. Presenting a meaningful if–then relationship even when this is coupled with a meaningless context produces significantly higher rates of the defective conditional interpretation that has been uniformly found to be the prime interpretation of conditionals. This in turn is entirely consistent with the hypothesis that a key component of processing conditionals is the inferential connection between the terms (Barrouillet & Lecas, 1998; Douven et al., 2017). In addition, the extent to which logical responses are produced when making conditional inferences with purely abstract premises is specifically related to the rate of defective conditional interpretations generated with basic conditionals. This suggests that processing meaningless conditionals requires a much more abstract form of representation. These results show that the most important aspect of inferential reasoning with abstract conditionals is not the familiarity of the terms used, but rather the indeterminate nature of the relationship expressed by such conditionals. While this study is not directly generalisable to a developmental context, it is interesting to note that these results are completely compatible with the developmental theory suggested by Markovits (2013).

Finally, it is interesting to note that the order effect observed suggests that activating the interpretation of conditionals has a clear effect on the inferences that are made, while there appears to be little effect in the opposite direction. This in turn suggests that the truth-table interpretation of conditionals represents a higher level of processing, which is consistent with the

idea that the truth-table task captures a higher level (metacognitive) representation of conditionals (Markovits, Thompson, & Brisson, 2015).

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