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Unless Reasoning

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We report the results of two experiments investigating conditional inferences from conditional *unless* assertions, such as *Juan is not in León unless Nuria is in Madrid*. Experiments 1 and 2 check Fillenbaum's hypothesis about the semantic similarity of *unless* with *if not* and *only if* assertions; both also examine inferential endorsements (Experiment 1) and endorsements and latencies (Experiment 2) of the four logically equivalent conditional formulations: *if A then B, if not-B then not-A, A only if B* and *not-A unless B*. The results of these experiments show the similarity of *unless* and *only if*, confirming that the representation of both conditionals from the outset probably include two possibilities directionally oriented from B to A; results also confirm the especial difficulty of *unless* assertions. The implications of the results are discussed in the context of recent psychological and linguistic theories of the meaning of *unless*.
Keywords: conditionals, propositional reasoning, mental models

Se presentan los resultados de dos experimentos que investigan las inferencias a partir de enunciados condicionales *a menos que*, tales como "Juan no está en León a menos que Nuria esté en Madrid". Los experimentos 1 y 2 comprueban la hipótesis de Fillenbaum sobre la similaridad semántica de los enunciados *a menos que* con *si no* y *sólo si*; ambos experimentos examinan las respuestas inferenciales (Experimento 1) y las respuestas inferenciales y las latencias (Experimento 2) de las cuatro formulaciones condicionales lógicamente equivalentes: *si A entonces B*, *si no-B entonces no-A, A sólo si B* y *no-A a menos que B*. Los resultados muestran la similaridad de *a menos que* y *sólo si*, confirmando que la representación de ambos condicionales probablemente incluya desde el principio dos posibilidades orientadas direccionalmente desde B a A; los resultados también confirman la dificultad especial de las afirmaciones del tipo *a menos que*. Las implicaciones de los resultados se comentan en el contexto de las teorías psicológicas y lingüísticas sobre el significado de *a menos que*.
Palabras clave: condicionales, razonamiento proposicional, modelos mentales

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Our aim is to examine some linguistic and psychological hypotheses about the meaning of *unless* conditionals by using conditional inference tasks. First, we outline a mental model theory of conditional reasoning and consider the possibilities people keep in mind to understand *if then* and *if not then* conditionals; we suggest that they represent only one of the possibilities from the outset to understand *if then* and *if not then*. Second, we examine the possibilities they think about in understanding *only if* conditionals and suggest that they represent two of the possibilities from the outset to understand them. Third, we review linguistic and psychological theories and evidence regarding *unless* and consider the possibilities people think about to understand this connective. We report two experiments that compare *unless* with *if then*, *if not then* and *only if*.

During the last four decades a great deal of psychological research has been devoted to propositional reasoning, particularly to conditionals. The study of how people reason from conditional statements has become the main concern of research in deductive reasoning (see, Evans, Newstead, & Byrne, 1993). Four main theoretical approaches have been posited in propositional reasoning. Mental rules theories claim that the reasoning process is based on the application of formal rules of inference (e.g., Braine & O'Brien, 1998; Rips, 1994). There is also a view claiming that conditional reasoning is based on domain-specific rules of inference (e.g., Fiddick, Cosmides, & Tooby, 2000; Holyoak & Cheng, 1995). The third approach, mental model theories, maintains that reasoning processes rely on the ability to imagine possibilities (e.g., Johnson-Laird & Byrne, 1991; Johnson-Laird & Byrne, 2002; see also Evans, 1993). The fourth view, related with mental models approach but neatly distinct, has been recently proposed by Evans and collaborators (Evans & Over, 2004; Evans, Over, & Handley, 2005). This view claims that the meaning of conditionals is represented by means of *epistemic* mental models that include not only the states of world but also "states of belief and knowledge" (Evans, in press). This paper is not aimed to contribute to the debate between diverse theories but to advance understanding about reasoning with *unless* and its meaning, from the mental model approach.

Most psychological work on conditionals has been centered on checking reasoners' abilities on three different experimental paradigms: the truth table task, Wason's selection task and the inferential rules task. The latter paradigm requires participants to construct or evaluate conclusions from the application of four conditional rules: *modus ponens* (MP), *denial of antecedent* (DA), *affirmation of the consequent* (AC), and *modus tollens* (MT) (see Table 1).

The studies reported here have been carried out from the perspective of mental model theory and have not aimed to contribute to the debate between mental rules and models. We will present some new empirical data using the inferential rules task to compare people's ability to reason with different conditional linguistic formulations.

Conditional Reasoning and Mental Model Theory

The mental model theory (Johnson-Laird & Byrne, 1991, 2002) holds that reasoning depends on the semantic processes of constructing and manipulating possibilities or models of sentences. Mental model theory of conditional reasoning (Johnson-Laird & Byrne, 2002) holds that people's reasoning may be explained according to two main

Table 1
The Truth Conditions for the Four Linguistic Forms and the Four Inferences from Them

	If A then B	A only if B	If not-B not-A	Not-A unless B
Truth conditions				
A and B	True	True	True	True
not-A and not-B	True	True	True	True
not-A and B	True	True	True	True
A and not-B	False	False	False	False
Inferences				
MP	A.·.B	A.·.B	not-B.·.not-A	A.·.B
AC	B.·.A	B.·.A	not-A.·.not-B	B.·.A
MT	not-B.·.not-A	not-B.·.not-A	A.·.B	not-B.·.not-A
DA	not-A.·.not-B	not-A.·.not-B	B.·.A	not-A.·.not-B

Note. MP = modus ponens, AC = affirmation of the consequent, MT = modus tollens, DA = denial of antecedent. Naming the four inferences for *unless* is difficult and we have been guided by the form of the minor premise and conclusion, as well as by the possibilities that are true and false. For *not-A unless B*, the three true possibilities are *A and B*, *not-A and not-B,* and *not-A and B*. The two logically valid inferences are *A therefore B*, and *not-B therefore not*-A. The two fallacies are *not-A therefore not-B*, and *B therefore A*. We call these inferences MP, MT, DA and AC respectively, although we accept that at first sight it may seem odd to use MP to refer to the inference *Not-A unless B*, *A therefore B*. Other naming schemes run into difficulties, however, and so we opt for this one.

principles. First, the principle of truth affirms that people keep in mind true possibilities or models, for example, for *if A then B: A and B*, *not-A and B*, *and not-A and not-B*; but not false possibilities, for example, *A and not-B*. The second principle maintains that in order not to overload working memory, people represent as little information as possible explicitly (Johnson-Laird & Byrne, 1991; Johnson-Laird, Byrne, & Schaeken, 1992). Thus, when reasoning from a conditional assertion such as *if A then B*, people keep in mind at the outset just the possibility mentioned in the conditional, *A and B* (see Table 2). If required, people may flesh out the representation of conditionals in order to make possibilities fully explicit:

A	B
not-A	B
not-A	not-B

This representation of conditional assertions corresponds to a *material implication* or one-way interpretation of conditionals. However, people frequently interpret *if then* statements as two-way conditionals or bi-conditionals. The initial representation of the *material equivalence* reading of *if then* assertions is the same as the one-way conditional. The only difference is that now the fully fleshed out possibilities are as follows:

A	B
not-A	not-B

Two of the model theory's main assumptions worth mentioning here are: First, the greater the number of explicit possibilities that reasoners have to keep in mind, the harder the task will be. Second, reasoning problems that can be solved from the initial possibilities of premises will be easier than those that demand a further fleshing out of the possibilities (Johnson-Laird & Byrne, 1991).

Mental model theory has precise predictions for the four rules of inference that have been traditionally posited from conditional assertions (Johnson-Laird & Byrne, 1991; 2002; see also Evans, 1993). The *Modus Ponens* (MP) rule of inference states that from the conditional statement *if A then B* and the categorical premise:

There is an A

the conclusion *there is a B* may be drawn. The situation represented in the categorical premise corresponds with the possibility people keep in mind initially when they interpret *if then* conditional assertions. Therefore, this inference will be easy since the conclusion can be directly extracted from this initial model.

A second valid conditional inference is *Modus Tollens* (MT). Now the categorical premise is:

There is not a B

and yields the conclusion *there is not an A*. The categorical premise eliminates the initial possibility, whose realization demands a fleshing out of models. Some reasoners are not going to make this more demanding working memory task and so erroneously conclude *nothing follows*. Others will go on thinking and build up a complete representation, in which the categorical premise corresponds to the situation described in the last model *not-A not-B*. This model clearly permits drawing out the *not-A* conclusion. MT inferences will obviously be harder since they require the extra cognitive work of fleshing out the models. These two inferences are valid for one-way conditionals as well as for biconditionals. The other two rules of inference, on the other hand, are valid only for biconditional interpretations. In the *Affirmation of Consequent* (AC), the categorical premise is:

There is a B

and the conclusion, *there is an A*, may be drawn from the first explicit model.

With the *Denial of Consequent* (DA) the categorical premise is:

There is not an A

and then the conclusion *there is not a B* requires one to flesh out the models, as in MT inferences. Hence mental model theory predicts that people will draw more AC inferences than DA ones.

When comparing MP and AC inferences, we see that they both allow the conclusion to be drawn from the initial representation. However, AC inferences are not valid for conditional interpretations, that is, they can be falsified by a full fleshing out of models: the model not-A B impedes the drawing of AC inference (B, then A). Moreover, AC inferences require reasoning in the direction opposite to the one in which the information from the conditional statement entered working memory (see, Evans, 1993; Johnson-Laird et al., 1992). Evans

Table 2
The Possibilities Reasoners Keep in Mind Initially when they Interpret the Four Linguistic Conditionals Formulations

If A then B	A and B
If not-B then not-A	not-B and not-A
A only if B	B and A not-B and not-A
Not-A unless B	not-B and not-A B and A

Note. The full set of true possibilities for each of the four linguistic forms is the same: *A and B*, *not-A and not-B,* and *not-A and B.*

holds that "subjects are inclined to focus attention on the part of the rule- antecedent or consequent- that is modified by the *if then* and reason from that component to the other" (1993, p. 9). A directional bias of this kind was proposed by model theory in syllogistic reasoning to account for the *figural effect* (Johnson-Laird & Bara, 1984) and has also been applied to propositional reasoning (Johnson-Laird, Byrne, & Schaeken, 1992). This directional bias, however, does not affect MP inferences, which can in addition be drawn from both conditional and biconditional interpretations. Therefore, the theory additionally predicts that MP inferences will be more frequent than AC ones, even in bi-conditionals in which the AC inferences are valid.

A relatively early result in the study of conditional inferences was that the basic difference in difficulty between MP and MT inferences tended to disappear when using *A only if B* conditional formulations (Evans, 1977; Evans & Beck, 1981). Mental model theory, following Braine (1978), developed an explanation that accounts for this result. Johnson-Laird and Byrne (1991) proposed that *only if* assertions lead from the start to two explicit representations (or models). They suggested people would have in mind from the outset two possibilities for *A only if B* conditionals as follows:

A	B
not-A	not-B

From this initial representation, reasoners can readily make both MP and MT. But, there are two empirical results that go against this explanation: First, people should make more DA from *only if* than from *if*, and they do not. Second, Evans (1977; Evans & Beck, 1981; see also Evans, Clibbens, & Rood, 1995) found that AC inferences were more frequent with *only if* conditionals than with *if then* ones. Evans (1993) holds that this increase in AC inferences could be explained by a directional bias produced by the order in which people build up the models. In order to explain both the lack of difference between MP and MT inferences for *only if* and *if then* assertions, and the increase of AC inferences for *only if*, Evans (1993; see also Santamaría & Espino, 2002; Grosset & Barrouillet, 2003) proposed that reasoners keep a single possibility in mind for *A only if B* but in the direction *B and A*, and thus have a processing preference for making inferences in accordance with this direction, from B to A. However, on this account reasoners should make fewer MT than AC from *only if*, and they do not.

In order to account for these two main empirical results, we have proposed an explanation that combines some aspects of other studies (Carriedo, García-Madruga, Moreno, & Gutiérrez, 1999; Egan, Byrne, & García-Madruga, 2007; García-Madruga, Gutiérrez, Carriedo, Moreno, & Johnson-Laird, 2002; García-Madruga, Moreno, Quelhas & Juhos, 2007). This proposal suggests that reasoners understand *only if* by thinking about *two* possibilities or models, as proposed by Johnson-Laird and Byrne (1991), but in the *directional* way proposed by Evans (1993). Thus, understanding *A only if B* would imply the construction of the two mental possibilities: *B and A* and *not-B and not-A* (see Table 2).

Finally, one problem in conditional inferences remains to be analyzed before turning to *unless* sentences: the negated conditionals. Johnson-Laird and Byrne (1991) proposed that the initial representation of negative conditionals would include the affirmative propositions. So, for instance, a conditional assertion with a negative consequent, such as:

If A, then not-B

will be represented with the following initial models:

A	not-B
	B

This kind of representation, suggested by the use of denial in language to correct misconceptions (Wason, 1965), has a basic advantage. It permits one to account for an important phenomenon found in truth tables and in Wason's selection task: the matching bias. However, the proposal of including the affirmative cases in the initial representation of conditionals cannot explain the results in conditional inferences. Therefore, Evans (1993; Evans, Clibbens, & Rood, 1996; Evans & Handley, 1999; Evans, Legrenzi, & Girotto, 1999) has proposed that there would be no difference between the representation of conditionals with and without a negative. Only the antecedent (positive or negative) and the consequent (positive or negative) are represented in the initial models. Hence, we will use this representation for negated conditionals throughout this paper (see Table 2).

An interesting result of research on negative *if* conditionals is that when using abstract materials there is a negative conclusion or *double negation* bias: Reasoners will make fewer affirmative inferences when their conclusion is an affirmative resulting from the denial of a negative (Evans et al., 1996; Evans & Handley, 1999; Evans et al., 1998; see also Schaeken & Schroyens, 2000; Schroyens, Schaeken, & D'Ydewalle, 2001). So, for instance, in a conditional in which the antecedent and consequent are negated, as in *if not-B then not-A* sentences we use in our experiments, the affirmative conclusions MT (*A then B*) and DA (*B then A*) will be more difficult: Both inferences demand the denial of an already negated term (MT: *A then not not-B*; DA: *B then not not-A*).

Unless Conditionals

Unless sentences are used in daily life and they occur in the pragmatic context of conditional warnings and threats (see Fillenbaum, 1976, 1986), for example:

You will not have an ice-cream unless you finish the meat.
Do not travel by car unless you take along chains.

Unless is a negative conditional connective directly related with *if not then* (see Quine, 1972; Reichenbach, 1947). In fact, from a logical point of view, an *if A then B* conditional assertion is equivalent to an *if not-B then not-A* conditional, and the latter could be correctly phrased with *unless* as: *not-A, unless B.*

Following Geis (1973) however, linguists offer compelling arguments against the identification of *unless* with *if not* (see, Dancygier, 1998, 2002; Declerck & Reed, 2000; Lycan, 2001). Geis holds that the meaning of *unless* is more similar to *except if* than to *if not* (see also von Fintel, 1991). In a similar way, Fillenbaum (1976, 1986), in trying to explain both the intimate relationship between *unless* and *if not* and their differences, proposed *only if* as the preferred understanding for *unless* sentences. So, the phrasing of the prior assertion using an *only if* formulation will be: *A only if B* (see Table 2). Other psychologists and linguists agree with the tight relationship between *only if* and *unless* conditionals (see for instance, Clark & Clark, 1977; Montolío, 1999).

There are few psychological studies of reasoning with *unless*. Wright and Hull (1986, 1988) carried out a series of experiments as to how people understand declarative sentences with *unless* and how they process instructions that include this conditional connective. Two of their ideas and results of their work deserve to be mentioned here.

First, Wright and Hull (1986, 1988) found a different pattern of results for *unless* and *if not then*, thereby confirming the differences between these two conditionals. Second, following Fillenbaum's proposals, they considered that the illocutionary force of *unless* is more similar to *only if* than to *if not then*. For example, if we choose a threatening sentence such as:

You will not have an ice-cream unless you finish the meat.

The illocutionary force of this sentence is focused on the desirability of the protasis (to finish the meat). This strong emphasis is partially lost when we use an equivalent *if not then* formulation:

If you don't finish the meat then you will not have an ice-cream.

On the contrary, if we consider an *only if* formulation:

You will have an ice-cream only if you finish the meat.

the main clause (to have an ice-cream) has lost its negative character, even though the strong emphasis of desirability on the need to *finish the meat* remains.

Semantic similarity between *unless* and *only if* was also confirmed in a preliminary study by Schaeken, García-Madruga, and d'Ydewalle (1997), although these authors found that solving conditional inferences with *unless* was harder than with *only if*. The special difficulty of *unless* conditionals results mainly from their tendency to produce asymmetric conclusions, while this is not the case for *only if*. As an example of these kind of asymmetric responses, some people gave the incorrect response *B* to the following set of premises: *not-A unless B*, and *not-A* (DA inference). Schaeken et al. maintain that a hypothetical explanation could be that these reasoners were using a shortcut strategy that consists of matching the two terms that appear in the statement. As we can see, Schaeken et al.'s results confirm Fillenbaum's hypothesis about the semantic similarity between *unless* and *only if* by constructing from the outset the same two models. However, the construction of the two initial models seems to be harder for *unless* than for *only if* as the asymmetric responses show.

In order to give account of prior evidence, we have proposed a two-initial-model representation for *unless* similar to that of *only if* (see table 2) (Carriedo et al., 1999; García-Madruga, Moreno, et al., 2002). We are not claiming that *only if* and *unless* sentences mean exactly the same thing. There is an obvious difference in the use of polarity between them: *only if* is affirmative, and *unless* is negative. In fact, in Spanish, *unless* sentences can be expressed indistinctly by "*a menos que"* and "*a no ser que,"* both expressions are relatively usual in Spanish, although "*a menos que*" tends to be more formal (see Montolío, 1999). The experiments of this paper used "*a menos que*." Related to the negative polarity of *unless* is its *counter-expectancy* nature (see Montolío, 1999, p. 3709). The previous threatening sentence, *You will not have an ice-cream unless you finish the meat*, does not imply a high expectancy by the speaker of the addressee finishing the meat and thereby getting the ice-cream (the affirmative possibility *B and A*). The aim of this work, however, is not to study these differences but to check the hypothesis of a similar core meaning by using an inference task with abstract conditionals.

Experiment 1

The objective of this experiment was to compare people's reasoning with the four logically equivalent conditional formulations: *If A then B*, *If not-B then not-A*, *A only if B* and *Not-A unless B*, by means of a within-subjects design that allowed a complete comparison between the four conditionals statements.

As we analyzed above, people build only one initial possibility or model for *if* and *if not* whereas they construct two models for *only if* and *unless*. Besides, we have proposed that the two model initial representation for *only if* and *unless* is backward, from B to A (see Table 2). From these assumptions we make our three main predictions:

1. There will be differences in accuracy between MP and MT inferences for *if then* and *if not then* statements, since MT cannot be drawn from the initial model. On the other hand, we predict no differences between MP and MT inferences for *unless* and *only if* since both inferences can be drawn from the initial representation.
2. The two model backward initial representation of *unless* and *only if* conditionals will yield an increase

in MT and AC inferences in comparison with *if then* and *if not then* statements.

As for DA inferences, we do not predict any increase for *unless* and *only if* conditionals in comparison with *if then* and *if not then* statements: The initial representation of the negated possibility (*not-B and not-A*) should facilitate DA inference, but this tendency can be cancelled out by the directional bias (from *B to A*).

3. Finally, given the special difficulty of *unless* statements checked in prior studies, we predict that reasoners will tend to give some asymmetric conclusions with *unless* formulations. This kind of responses is not predicted for the other conditional formulations.

Method

Participants

Thirty-two third year psychology students from a class at the Universidad Nacional de Educación a Distancia (UNED) in Madrid voluntarily participated in the experiment for course credit. The participants had received no training in logic and had not been previously tested in any experiment in reasoning. Six participants were replaced because they incorrectly answered all four questions in at least two conditions.

Materials

A list of 70 problems with different types of conditionals were created. Six of the 70 were presented as practice items and the other 64 were presented as experimental items: 16 sentences corresponding to *if A then B*, 16 to *if not-B then not-A*, 16 to *not-A unless B*, and the other 16 to *A only if B*. The six practice problems consisted of one for *if* and *if not* and two for *only if* and *unless* conditionals; there were one example of MP and AC inferences and two examples of DA and MT inferences. Participants did not receive any feedback after practice problems.

The lexical content of the problems referred to the locations of letters on one side of a card and numbers on the other side of a card. The lexical form of each type of conditional statement was as follows:

If there is a P on one side, there is a 1 on the other side. (In Spanish: "Si hay una P por un lado, hay un 1 por el otro lado").

If there is not a 1 on one side, there is not a P on the other side. (In Spanish: "Si no hay un 1 por un lado, no hay una P por el otro lado").

There is not a P on one side, unless there is a 1 on the other side. (In Spanish: "No hay una P por un lado, a menos que haya un 1 por el otro lado").

There is a P on one side only if there is a 1 on the other side. (In Spanish: "Hay una P por un lado sólo si hay un 1 por el otro lado").

For each statement, letters and numbers were randomized, so participants were never exposed to the same letter-number combination. Each type of conditional occurred four times, corresponding to the MP inference, 4 MT, 4 DA and 4 AC. The negative minor premises were explicit negations, for example, *If there is a P on one side, there is a 1 on the other side, There is <u>not</u> a P on one side* (DA).

Design

Participants acted as their own controls. Each subject had to respond to 64 conditionals problems in which there were 4 types of conditional statements—*if A then B, if not-B then not-A, not-A unless B*, and *A only if B*—and 4 types of inferences: MP, AC, MT, and DA. Thus a 4×4 within-subjects design was used.

Procedure

Participants were tested individually in a single session lasting approximately an hour. The instructions explained the nature of the task. Participants were told that they had to state what, if anything, followed necessarily from each set of premises, i.e., what <u>must</u> be true given that the premises were true. If the participants considered that nothing followed from the premises, then they had to write that nothing follows. The entire procedure, including all instructions, was controlled by a Macintosh computer.

Participants sat in front of a video display screen on which the written information appeared in black capital letters on a white screen. After having read carefully the instructions, and completed the practice trials, one of the four kinds of conditional sentences appeared on the screen. Participants had to read the sentence and press the space bar in order to change the display. Then the categorical premise appeared on the screen in one of the MP, MT, DA or AC variants. Participants, after reading the categorical premise, had to press the space bar, and then the following question appeared: "What is the conclusion?," to which they had to write down the conclusion. There was no option of backtracking through the display. The computer recorded the answer written by participants.

Results and Discussion

Data were analyzed using non-parametric Wilcoxon's tests and all comparisons were one-tailed, unless otherwise stated.

We computed the percentage of inferences MP, DA, AC and MT endorsed by participants to determine the accuracy of responses. Apart from the inferential answers, people

gave other types of responses as well, for example blank responses, asymmetrical answers of the kind found by Schaeken et al. (1997), and particularly the "There is no valid conclusion" answer, that is logically correct for DA and AC. The percentages of endorsed inferences are shown in Table 3.

People endorsed a higher overall percentage of inferences for *A only if B* (80%) than for the other kind of conditional formulations: *not-A unless B* (76%), *if A then B* (75%) and *if not-B then not-A* (69%). However, there were no significant differences among them (Friedman ANOVA test: $\chi^2(26, 3) = 5.13$, $p < .16$, two-tailed).

As expected, results show that as for *if then* and *if not then*, the difference between MP and MT inferences was reliable ($z = 2.4$, $p < .008$ and $z = 1.91$, $p < .023$, respectively). On the contrary, there was no reliable difference between MP and MT inferences for *unless* ($z = 0.22$, $p > .1$, two-tailed), and nor for *only if* ($z = 1.60$, $p > .05$, two-tailed).

Likewise, according to our expectations, MT for *unless* statements were easier than MT for *if not then* (z = 1.64, $p < .05$); the same predicted pattern, although lacking significance, appeared in the comparison between MT for *unless* and for *if then* ($z = 1.08$, $p < .14$). Likewise, MT inference with *only if* statements were reliably easier than MT for *if not then* (z = 1.81, $p < .035$), although the difference between MT for *only if* and for *if then* was not reliable ($z = 0.87$, $p < .19$).

There was also a general increase in AC inferences both for *unless* and for *only if* in comparison with *if then* and *if not then* statements. AC inferences for *unless* were easier than AC for *if then* and for *if not then*, although the difference was reliable only for the latter ($z = .11$, p < .50 and $z = 2.39$, $p < .01$, respectively). In a similar way, AC inferences with *only if* were easier than AC for *if then* and for *if not then*, although the difference was also reliable only for the latter ($z = 1.14$, $p < .13$ and $z = 3.05$, $p < .002$, respectively).

Concerning DA inferences, a Friedman ANOVA test showed that there were no differences among the four conditional formulations, $\chi^2(26, 3) = 5.68$, $p > .1$, two-tailed.

As expected, there was a relevant percentage of asymmetric conclusions with *unless* conditionals (15.4%), reliably higher than those found with the other conditional formulations (*If then*: 2.9%; *If not then*: 6.3%; and *Only if*: 2.9%; $z = 2.29$, $p < .01$; $z = 1.73$, $p < .05$; and z = 2.71, $p < .003$, respectively). The highest percentage of overall asymmetric responses was for *unless* DA inferences (23%).

Our predictions tend to be confirmed by the results found. Firstly and most importantly, mental model hypothesis was almost completely confirmed. There were reliably more MP inferences than MT ones for *if then* and *if not then* conditionals. On the other hand, there were no differences in accuracy between MP and MT for *unless* and for *only if*.

The same pattern of almost universal confirmation was found with the second prediction concerning MT and AC inferences. MT inferences were reliably more frequent with *unless* and *only if,* than with *if not then*. Likewise, MT inferences were more frequent with *unless* and *only if* than with *if then*, although these differences were not totally reliable. On the other hand, we have also confirmed the increase in AC inferences for two-model assertions: AC inferences were reliably more frequent with *unless* and *only if,* than with *if not then*. Likewise, AC inferences were more frequent with *unless* and *only if* than with *if then*, although these differences were not totally reliable.

Our prediction concerning the asymmetric responses to *unless* was also confirmed. We found a relevant amount of asymmetric responses with *unless* conditionals, particularly high with DA inferences, that confirm the difficulty of understanding and reasoning from this formulation. The reliably higher percentage of these responses with *unless* than with the others formulations replicate prior results (Schaeken et al., 1997; Carriedo et al., 1999; García-Madruga, Moreno, et al., 2008).

As for DA inferences, there were no significant differences among the diverse conditional formulations. Therefore, as in prior studies (see, Evans, 1977; Schaeken et al., 1997) there is no increase of DA inferences in *only if* and *unless* formulations. We will discuss the case of DA inferences more in depth below.

Summing up, results tend to confirm our idea that *A only if B* and *not-A unless B* probably lead people to imagine two possibilities from the outset, and that these possibilities go in the opposite direction than in the case of *if A then B*; that is, from *B to A* not from *A to B*.

Table 3
Percentages of Conclusions Endorsed by Participants in Experiment 1

Endorsements	MP	AC	MT	DA
	A.·.B	B.·.A	notB.·.notA	notA.·.notB
If A then B	95	69	77	62
A only if B	91	78	83	66
Not-A unless B	83	71	85	67
	notB.·.notA	notA.·.notB	A.·.B	B.·.A
If not-B then not-A	86	67	68	56

Note. MP = modus ponens, AC = affirmation of the consequent, MT = modus tollens, DA = denial of antecedent.

Experiment 2

The purpose of this second experiment was to test our main predictions with a new procedure that allows the computation of not only participants' accuracy but also their response latencies. We changed the task in such a way that participants, instead of drawing their own explicit conclusion, had to evaluate whether a given conclusion was true or false. That is, we replaced the construction task of Experiment 1 with an evaluation task in the present experiment, using the same procedure as in Wright and Hull (1986) in which reading time of minor categorical premise (MP, AC, DA, or MT) and response conclusion was recorded together. Hypotheses one and two are the same as in Experiment 1. As participants now only had to evaluate the given conclusion, the third hypothesis regarding the asymmetric responses was skipped and substituted by a new hypothesis concerning response latencies. Espino, Santamaría, and García-Madruga (2002; see also Grosset & Barrouillet, 2003) demonstrated the existence of an opposite directional effect for *if A then B* than for *A only if B*: Reasoners were faster drawing inferences from *A to B* for *if then* and from *B to A* for *only if*. The directional effect is enclosed in our proposed representation (see Table 2) and thus we predict that latencies from *B to A* will be faster for *A only if B*, *not-A unless B,* and *If not-B then not-A*. Conversely, we predict an *A to B* directional effect for *if A then B*.

Method

Participants

Thirty-three volunteers participated in the experiment. Participants were students of Psychology of UNED. They received a credit for taking part in the experiment. Two participants were replaced because they incorrectly answered all four questions in at least two conditions.

Design and Materials

They were the same as in Experiment 1, except for the task used. Now participants are asked to evaluate the conclusions.

Procedure

Participants were tested individually in a single session lasting approximately 45 minutes. Participants were instructed about the nature of the task, they were told that they had to decide whether the conclusions of the inferences were "necessarily true," "false," or "nothing follows." The entire procedure, including all instructions, was controlled by a Macintosh computer. Participants sat in front of a video display screen on which the written information appeared in black capital letters on a white screen.

After having carefully read the instructions and completed some practice trials, one of the four types (MP, AC, DA, or MT) of conditional sentences appeared on the screen. Participants had to read the sentence and press the space bar to change the display, at which time the categorical premise appeared on the screen, thus indicating one of the four (MP, MT, DA, or AC) inference types. Again, participants, after reading the categorical premise, had to press the space bar, at which time the word CONCLUSION appeared followed by the conclusion for the particular conditional inference (MP, MT, DA, or AC). Participants had to respond by pressing one of three different keys: A key labeled with the word "YES" if they thought that the conclusion was true, a key labeled with the word "NO" if they thought that the conclusion was false, and the space bar if they thought that there was no valid conclusion.

There were no options of backtracking through the display. Participants were instructed to read each sentence carefully and then respond to the question as quickly as possible. The computer recorded the time (in milliseconds) in which all the keys were pressed and the answer given by participants.

Results

Data were analyzed using non-parametric Wilcoxon's tests and all comparisons were one-tailed, unless otherwise stated.

Accuracy of Responses

There were significant differences in the overall percentage of endorsed inferences for the four conditional assertions (Friedman ANOVA test: $\chi^2(31, 3) = 8.647727$ $p < .034$, two-tailed). The overall percentage of *A only if B* endorsements (85%) was significant higher than those of *if not-B then not-A* (72%) and *not-A unless B* (76%), and marginally higher than *if A then B* (78%), $z = 3.37$, $p < .0005$; $z = 2.41$, $p < .02$; and $z = 1.89$, $p < .057$; two tailed, respectively. Likewise, there were more endorsed inferences for *if A then B* than for *if not-B then not-A*, although the difference was marginal, $z = 1.8$, $p < .060$, two-tailed. The percentage of *not-A unless B* inferences was not significantly different than the percentage of *if A then B* nor *if not-B then not-A* inferences.

Percentages of endorsed inferential responses appear in Table 4. It seems clearly easier for participants to make MP than MT inferences, both for *if then* ($z = 3.18$, $p < .001$) as for *if not then* ($z = 3.37$, $p < .001$). However, neither resulted in differences between MT and MP inferences with *unless* ($z = 1.47$, $p > .10$, two-tailed) nor with *only if* ($z = 0.49$, $p > .10$, two-tailed).

Table 4
Percentages of Conclusions Endorsed by Participants in Experiment 2 and Response Latencies (in Seconds)

Endorsements	MP	AC	MT	DA
	A.·.B	B.·.A	notB.·.notA	notA.·.notB
If A then B	98	75	78	63
A only if B	94	89	90	69
Not-A unless B	76	86	86	56
	notB.·.notA	notA.·.notB	A.·.B	B.·.A
If not-B then not-A	96	64	63	66
Latencies				
	A.·.B	B.·.A	notB.·.notA	notA.·.notB
If A then B	2.5	3.9	5.5	5.0
A only if B	3.3	2.9	3.9	4.7
Not-A unless B	4.2	3.0	4.6	5.4
	notB.·.notA	notA.·.notB	A.·.B	B.·.A
If not-B then not-A	3.4	5.3	5.6	4.6

Note. MP = modus ponens, AC = affirmation of the consequent, MT = modus tollens, DA = denial of antecedent.

Concerning MT inferences, there was no reliable difference between MT inferences with *unless* and with *if then* (z = 1.25, $p > .10$), although the tendency was in the predicted direction: MT inferences seem to be easier with *unless* than with *if then*. However, the difference between MT inference with *if not then* and MT with *unless* was reliable (z = 2.62, $p < .004$). Likewise, it seems reliably easier to make MT inferences with *only if* than with *if then* (z = 2.38, $p < .008$), and with *if not then* (z = 3.05, $p < .001$).

As in Experiment 1, there was a general increase in AC inferences both for *unless* and for *only if* in comparison with *if then* and *if not then* statements. Thus AC inferences for *unless* were easier than AC for *if then* and for *if not then*, and this time the former just missed the significance level ($z = 1.48$, $p < .07$; and $z = 3.24$, $p < .001$, respectively). AC inferences with *only if* were reliably easier than both AC for *if then* and for *if not then* ($z = 2.02$, $p < .05$; and $z = 3.03$, $p < .002$, respectively).

Concerning DA inferences, there were no differences among the percentage of endorsements for the four conditional formulations, as shown by Friedman ANOVA test, $\chi^2(31, 3) = 2.68$, $p < .44$, two tailed.

Latencies

Latency analyses were undertaken by combining the time spent reading the categorical premise and answering the question, that is, responding whether the conclusion was true or false, independently of whether the response was logically valid or not. This is the same procedure used by Wright and Hull (1986). Data for the analysis were generated by calculating medians. Extremely long latencies that exceed 20 seconds were excluded from the analysis. According to this criterion, 1.37% of the scores were eliminated. The sentence distribution of eliminated latencies was: 17.24% in *if then*, 24.14% in *if not then*, 27.6% in *unless*, and 31.3% in *only if*. Empty cells were replaced by the mean of the row (participant's overall performance) and the column (condition) means.

There were significant differences in the overall latencies for the four conditional assertions (Friedman ANOVA test: $\chi^2(31, 3) = 22.55$, $p < .0001$, two-tailed). The overall latency of *A only if B* inferences (3.7 s) was significantly faster than that of *if not-B then not-A* (4.7 s) and *not-A unless B* (4.3 s), and marginally faster than *if A then B* (4.2 s), $z = 4.33$, $p < .0001$; $z = 3.48$, $p < .001$; and $z = 1.94$, $p < .053$, two-tailed, respectively. Likewise, response latencies for *if not-B then not-A* were slower than for *if A then B* and *not-A unless B*, although the latter difference was marginal, $z = 2.88$, $p < .01$ and $z = 1.92$, $p < .055$, two-tailed, respectively. Response latencies for *not-A unless B* were not significantly different from the latencies for *if A then B*.

For *if*, response latencies for inferences from *A to B* (MP and DA) were faster (3.8 s) than response latencies for inferences from *B to A* (AC and MT: 4.7 s; $z = 3.10$, $p < .001$). Conversely, for *only if*, *unless* and *if not*, *B to A* response latencies were faster than *A to B* response latencies (*only if* 3.4 and 4.0 s, respectively; $z = 3.94$, $p < .0001$; *unless*: 3.8 and 4.8 s, respectively; $z = 3.20$, $p < .001$; and *if not*: 4.0 and 5.5 s, respectively; $z = 3.45$, $p < .0005$).

Time required to make MP inferences was reliably shorter than the time to make MT inferences for *if then* ($z = 4.56$, $p < .001$) and for *if not then* ($z = 3.88$, $p < .001$). Moreover, no difference was found between the time required to make MT and MP inferences for *unless* (z = 1.27, $p > .10$, two-tailed). However, contrary to our predictions, significant differences between the time required to make MT and MP inferences were found for *only if* (z = 2.97, $p < .01$, two-tailed).

Concerning the response latencies for MT inferences, the results obtained clearly confirm our predictions. Participants made reliably faster MT inferences with *only if* than MT inferences with *if then* and *if not then* (z = 3.15, $p < .01$ and z = 3.99, $p < .001$, respectively). Although the comparison between the time required to make MT with *unless* and MT with *if then* was only marginally significant (z = 1.45, $p < .07$), participants were reliably faster drawing MT inferences with *unless* than MT with *if not then* (z = 1.67, $p < .05$).

On the other hand, as expected, AC inferences for *unless* were reliably faster than AC for *if then* and for *if not then* ($z = 2.31$, $p < .01$, two tailed; and $z = 4.03$, $p < .001$, respectively). Likewise, AC inferences with *only if* were reliable faster than both AC for *if then* and for *if not then* ($z = 3.17$, $p < .001$ and $z = 4.70$, $p < .001$, respectively).

Concerning DA inferences, there were no differences in latencies among the four conditional formulations as shown by Friedman ANOVA test, $\chi^2(31, 3) = 4.90$, $p > .10$, two-tailed.

Discussion

First of all we want to emphasize that results show a fine match between response latencies and accuracy measures. Therefore, the main objective of this experiment was reached. As in Experiment 1, people endorsed a higher overall percentage of inferences for *A only if B* than for the other kind of conditional formulations, but now most of differences were reliable. *Unless*, in particular, was harder than *only if*, replicating prior results (Schaeken et al., 1997; Carriedo et al., 1999; García-Madruga, Moreno, et al., 2008) and thereby confirming the especial difficulty of *unless* formulations. Moreover, these results were tightly borne out by response latencies.

Concerning our predictions, the first one was almost completely confirmed. There were reliably more and faster MP inferences than MT inferences for *if then* and *if not then* conditionals. On the other hand, there were neither accuracy nor latency differences between MP and MT for *unless*. For *only if*, although there were no differences in accuracy, MP tended to be faster than MT. This latter result may be produced by some of the participants giving their response from a superficial matching with the two values mentioned in the assertion (*A only if B*).

The same pattern of almost universal confirmation was found with the second prediction. MT inferences tended to be more frequent and faster with *unless* than with *if then* and *if not then*. The same can be said as for *only if* MT inferences in relation to *if then* and *if not then*. Likewise, there was also a consistent increase in the amount and swiftness of AC inferences with two-model conditional assertions.

Our third hypothesis was also borne out: Response latencies showed a *forward* directional effect from *A to B* for *if*, and a *backward* effect, from *B to A*, for *A only if B*, *not-A unless B* and *If not-B then not A*. This directional effect should therefore be included in the mental model theory (see Evans, 1993; Grosset & Barrouillet, 2003; Santamaría & Espino, 2002). The opposite directional effect for *if A then B* (from *A to B*) and *if not-B then not-A* (from *B to A*) may be explained as due to the opposite order in which the information enters working memory (see Johnson-Laird & Bara, 1984; Johnson-Laird & Byrne, 1991). But, the directional effect from *B to A* for *not-A unless B* and *A only if B* demands that mental models are considered as oriented relations, as Grosset and Barrouillet (2003) have claimed (see also Espino et al., 2000). The results found for *A only if B* and *not-A unless B* suggest that the determinant role in establishing the directionality of the relation between the terms of conditional may be probably played not by the order information enters working memory, but by the word that acts as connective: *if* and *unless* (see Evans, 1993).

As in Experiment 1, there were no significant differences in DA inferences among the four conditional assertions, both in the percentage of endorsements and the latencies. Summing up, the results of Experiment 2 clearly confirm our predictions. They also replicate the accuracy findings of Experiment 1, and reinforce them with latency measures in the same direction.

General Discussion

We have tested Fillenbaum's hypothesis about the mental representations and processes that underlie making inferences with *unless* conditionals. Fillenbaum's view emphasises the differences between *unless* and *if not*, claiming a close similarity between *unless* and *only if* conditionals. From the mental model theory, this hypothesis leads to precise representational assumptions. On the one hand, according to model theory, *if* conditionals are initially understood by keeping in mind a single possibility, corresponding to the true possibility whose elements are mentioned in the conditional. *If A then B* is understood by initially keeping in mind the possibility *A and B*; *if not-B then not-A* is understood by initially keeping in mind the possibility *not-B and not-A* (Johnson-Laird & Byrne, 2002). On the other hand, we suggested that *only if* and *unless* are both understood by keeping in mind two possibilities, corresponding to the true possibility whose elements are mentioned in the conditional, and the true possibility whose elements are the negation of those mentioned in the conditional. Moreover, our proposed representation includes a backwards B-A direction rather than a forwards A-B direction. *Not-A unless B* and *A only if B* are understood by initially keeping in mind *B and A* and *not-B and not-A*.

The results of Experiments 1 and 2 are consistent with predictions derived from this view. The results corroborate our suggestion that the second possibility is available for

only if and *unless*, but not for *if* and *if not*. The results provide two strands of support for our conjectures:

1. People endorse more inferences for MP than MT (Experiment 1 and 2), and MP response latencies are faster than MT inferences (Experiment 2) for *if* and *if not*. For *unless* and *only if*, however, there were no differences between MP and MT endorsed inferences for *unless* and *only if* (Experiments 1 and 2); likewise, MP and MT response latencies were not different for *unless*, although the response latency for MP was faster than MT for *only if*.
2. People endorse more MT and AC inferences for *unless* and *only if* conditionals than for *if then* and *if not then*. Although all the differences go in the predicted direction, some did not reach significance, particularly those in Experiment 1. In exp 2, MT and AC response latencies for *unless* and *only if* are faster than for *if* and *if not*. The few anomalies primarily concern *if* conditionals and may be affected by the higher familiarity of *if* assertions in comparison with *only if* and *unless*.

Our results provide evidence against alternative views of *unless* and *only if*. They rule out that *not-A unless B* and *A only if B* are understood as *if not-B then not-A*. This view cannot explain the higher and faster MT and AC inferences for *unless* and *only if*. Moreover, our results also rule out the suggestion that reasoners keep a single possibility in mind for *A only if B*, but in the backward direction *B and A* (Evans, 1993; Grosset & Barrouillet, 2003; Santamaría & Espino, 2002). This idea predicts higher and faster AC inferences as we have found, but not a similar increase for MT inferences. Moreover, this account assumes that reasoners should make more AC (*B therefore A*) than MT (*not-B therefore not-A*) inferences from *only if* and they do not: In both experiments participants endorsed more MT than AC inferences, although the differences were not significant. The same can be said for *unless*. As we mentioned before, our account reunites the claim that reasoners keep two possibilities in mind to understand *A only if B* (Johnson-Laird & Byrne, 1991), with Evan's suggestion that the two possibilities reasoners keep in mind are directionally sensitive, *B and A,* and *not-B and not-A* (Carriedo et al., 1999; García-Madruga et al., 2002; García-Madruga, Moreno, et al., 2008). Therefore, according to our account each possibility or model represents relations directionally oriented (Grosset & Barrouillet, 2003) and this direction is probably established from the word that states the connective, this being *if* as in *if A then B*, *If not-A then not-B*, and *A only if B*, or *unless* as in *not-A unless B*.

Fillenbaum's hypothesis about the meaning of *unless* allowed us to make a number of precise predictions, most of which have been confirmed in Experiment 1 and 2. However, the results of these experiments may be also accommodated by a more recent hypothesis proposed by Dancygier (1998; see also Traugott, 1997). Dancygier maintains that *not-A unless B* is interpreted as two different statements: one claiming *not-A* and the other expressing the unique circumstances (B) under which *A* might occur. According to this view, the representation of *not-A unless B* would hence include the following two possibilities:

not-A
B and A

From the second affirmative model, MP (*A, then B*) and AC (*B, then A*) inferences may be directly drawn. Likewise, MT (*not-A, then not-B*) may be easily inferred since the *not-B* categorical premise can be directly connected with the first incomplete model. However, in DA (*not-A, then not-B*), where the categorical premise *not-A* is presented, reasoners have to complete the first model in order to obtain the conclusion. Therefore, Dancygier's hypothesis would yield a decrease of DA inferences.

According to model theory, the difference between Dancygier and Fillenbaum's hypotheses about *unless* would mainly affect DA inferences. Following Fillenbaum's claim, we have proposed that people represent *not A unless B* (and *A only if B*) by constructing the two complete possibilities: *B and A* and *not-B and not-A* (see Table 2). Apart from the directional bias against DA, from this representation we should not expect a relevant difference between the endorsement of DA and the other inferences for *unless*. In fact there are no reliable differences among the four inferences for *unless* in Experiment 1. However, DA percentages of endorsed inferences are the lowest in Experiment 1, and reliably lower than the rest in Experiment 2, and these results are also confirmed with latencies: DA latencies are the highest for *unless*. Therefore, our results seem to show some evidence in favor of the incomplete representation of negative model proposed by Dancygier.

The experiments in this paper bear out the difficulty of *unless* assertions. In spite of the intimate relations between *unless* and *only if*, Experiment 1 and 2 indicate that *not-A unless B* is not entirely the same as *A only if B* (pace Fillenbaum, 1986). In Experiment 1 reasoners made more asymmetric errors from *unless*, in Experiment 2 they made fewer and slower inferences from *unless* (Carriedo et al., 1999; García-Madruga et al., 2002; see also Schaeken et al., 1997). The asymmetrical responses imply a complete misunderstanding of the meaning of *unless* and may likely be result of a sort of superficial bias or strategy. García Madruga and colleagues (García-Madruga, Gutiérrez, Carriedo, Vila, & Luzón, 2007) have demonstrated that asymmetrical responses are given less by high working memory subjects than by low working memory subjects, thereby showing its superficial and heuristic nature. High working memory subjects are able to resist and inhibit these kinds of responses.

Our experiments give some further evidence to the way people think about *unless*. People usually express warnings

and threats using *unless* assertions. However, until very recently, psychologists have not paid attention to *unless* conditionals. The assertion *You won't pass the exam unless you work harder,* conveys subtly different information from the assertion, *If you don't work harder then you won't pass the exam*. We suggest that reasoners initially keep one possibility in mind to understand the latter but not the former. Likewise, following Fillenbaum and Dancycier, we claim that the meaning of *You won't pass the exam unless you work harder* is more similar to *You will pass the exam only if you work harder*. In the two cases, people keep in mind two possibilities. We claim that these possibilities are: one conjecture about *working harder and passing the exam* and another about the probable result of *not passing the exam*. Our results seem to confirm that, for *unless*, this second possibility or model may be incomplete. Dancygier's idea agrees with the cognitive-economy principle in mental model theory claiming that people represent as little information as possible explicitly (Johnson-Laird & Byrne, 1991; Johnson-Laird et al., 1992). An interesting line of research in the future would be to check whether people represent a second incomplete possibility when entertaining *only if* assertions. The idea that reasoners keep a second but incomplete possibility in mind, would probably account for the partially contradictory evidence about this second possibility or model for *A only if B* (see Evans, 1993; Grosset & Barrouillet, 2003; Santamaría & Espino, 2002). The comparison of *unless* assertions with other conditional formulations in diverse pragmatic contexts is another interesting line of research on which we are working. In this line, the subtle variation in information conveyed by *if*, *if not* and *only if* assertions have been recently analyzed by Hilton, Kemmelmeir and Bonnefon (2005), in the pragmatic context of instructions given by a boss to employee.

As we said in the Introduction, a difference between the meanings of *unless* and *only if* sentences comes from the *counter-expectancy* nature of *unless*. This counter-expectancy affects the different expected probability of the affirmative possibility *B and A*: The probability of the affirmative possibility of *working harder and passing the exam* is higher when using an *only if* promising sentence than when using an *unless* threatening sentence. In fact, the results of both experiments show that affirmative inferences, particularly MP, tend to be lower for *unless* than for *only if*. The difference in the expected probability of the affirmative possibility between *unless* and *only if* might be explained by mental model theory in terms of *pragmatic modulation*: The activation or availability of the affirmative possibility would be higher for *only if* than for *unless*. In fact, this difference comes from the different socio-pragmatic context of using either "promises" or "threats" and this pragmatic context may vary according to socio-cultural patterns of linguistic communication.

The different expected probability of the affirmative possibility accommodates fairly well with Evans and col.'s recent theory of conditionals (Evans & Over 2004; Evans et al., 2005), which includes suppositional values in the representation of the possibilities in terms of *epistemic* models (Evans, in press). The results of both experiments could easily be explained from a similar two-model representation for *unless* and *only if*. This representation, however, would enclose different suppositional values for both statements. Another main theoretical issue posed by Evans and cols.'s theory of conditionals is the effect of *double negation* in negative conditionals (see Evans et al., 1996; see also Evans & Over, 2004). According to this double negation effect, MT (*A then B*) and DA (*B then A*) should be more difficult for *if not-B then not-A* since they demand the denial of an already negated term (MT: *A then not not-B*; DA: *B then not not-A*). The pattern of results for *if not-B then not-A*, in both experiments, seem to confirm a lower percentage of MT (*A then B*) and DA (*B then A*) inferences in comparison with MT (*not-B then not-A*) and DA (*not-A then not-B*) inferences for *if A then B*. As for *not-A unless B* the double negation effect should affect AC inference since it also demands the denial of an already negated term (*B then not not-A*). In this case, in both experiments, the AC (*B then A*) inference tends also to be lower for *not-A unless B* than for *only if*. Therefore, we may conclude that although the results of our experiments give evidence in favor of a two possibilities representation for *unless* and *only if*, they do not rebut the main assumptions of the most recent Evans and col.'s theory of conditionals.

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