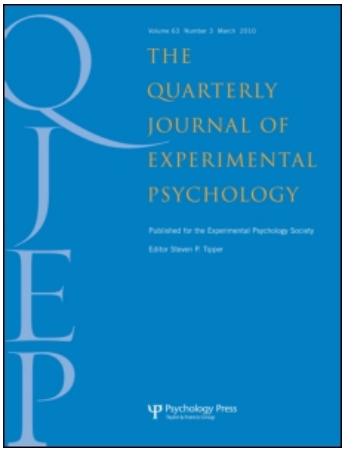

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People think about what is true for conditionals, not what is false: Only true possibilities prime the comprehension of "if"

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Short article

People think about what is true for conditionals, not what is false: Only true possibilities prime the comprehension of "if"

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We report the results of two priming experiments that examine the comprehension of conditionals—for example, "if there are apples then there are oranges"—and biconditionals—for example, "if and only if there are apples then there are oranges". The first experiment showed that participants read a biconditional faster when it was primed by a true possibility, "there were apples and there were oranges" than when it was primed by a false possibility, "there were no apples and there were oranges"; a conditional was primed equally by both possibilities. The second experiment showed that participants read the negated-antecedent conjunction faster when it was primed by a conditional than when it was primed by a biconditional; the affirmative conjunction was primed equally by both connectives. The experiments show that (a) when people understand "if A then B", they access the true possibilities, "A and B", and "not-A and B", and (b) when they understand "if and only if A then B" they access "A and B", but they do not access "not-A and B". We discuss their implications for current theories of reasoning.

Keywords: Reasoning; Conditional; Biconditional; Mental model theory; Suppositional theory.

A key question for understanding human cognition is whether people have a natural tendency to think about what is true rather than what is false. A tendency to think about what is true has consequences for many aspects of how people reason (Byrne, 2005; Johnson-Laird, 2006). People may reason by thinking about possibilities, and they may tend to envisage true possibilities rather than false possibilities (Johnson-Laird & Byrne, 2002). They understand a conditional—for example, "if there are apples in the market then there are oranges" (if A then B)—by envisaging the true possibility that is consistent with the conditional, "there are apples and there are

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oranges" (A and B; Johnson-Laird & Byrne, 2002). They can also think about other true possibilities—for example, "there are no apples and there are no oranges" (not-A and not-B) and "there are no apples and there are oranges" (not-A and B). However, they do not think about the possibility that it rules out—"there are apples and there are no oranges" (A and not-B). The possibilities that they think about may be mentally represented in mental models (Johnson-Laird & Byrne, 1991).

Different connectives are consistent with different possibilities. The biconditional, "if *and only if* there are apples in the market then there are oranges" (if and only if A then B) is consistent with just the first two true possibilities above. People do not think about the two possibilities ruled out by the biconditional—"there are no apples and there are oranges" (not-A and B) and "there are apples and there are no oranges" (A and not-B). A strong prediction can be derived from the model theory: People should have greater access to the possibility "there are no apples and there are oranges" (not-A and B) when they understand a conditional than when they understand a biconditional, as Table 1 illustrates. This possibility is consistent with the conditional but not with the biconditional, and people think about only the true possibilities.

An alternative view is that people understand a conditional "if there are apples in the market then there are oranges" (if A then B) by thinking about the possibilities that include its antecedent (A)—that is, "there are apples and there are oranges" and "there are apples and there are no oranges" (Evans & Over, 2004; Evans, Over, & Handley, 2005). They do not think about the possibilities that do not include the antecedent, "there are no apples and there are oranges" and "there are no apples and there are no oranges", which are considered irrelevant.

A further claim of this account is that a biconditional "if and only if there are apples in the market then there are oranges" is understood in the same way as the conditional above, but also taken together with a second converse conditional "if there are oranges then there are apples" (if B then A; Evans et al., 2005). People think about the same two possibilities for the biconditional as for the conditional (A and B, and A and not-B), and in addition they think about an extra possibility that contains the antecedent of this second conditional, "there are oranges and there are no apples" (B and not-A). The prediction derived from the suppositional theory is the opposite to that derived from the model theory—that is, people should have greater access to the possibility "there are no apples and there are oranges" (not-A and B) when they understand a biconditional than when they understand a conditional, as Table 1 illustrates.

Do people keep in mind true possibilities or possibilities that contain the antecedent of a conditional? The aim of the two experiments reported in this paper is to pit the predictions of the two theories against each other. The two experiments rely on a priming methodology: We measured the length of time it took people to read a conjunction—for example, "there are no apples and there are oranges"—after they had first been primed by a conditional "if there are apples then there are oranges" compared with when they had been primed by a biconditional "if and only if there are apples then there are oranges" (Santamaría & Espino, 2002; Santamaría, Espino, & Byrne, 2005). We also measured the length of time it took them to read a conditional or biconditional after they were first primed by the conjunction. We focused on the key distinguishing possibility, not-A and B.

Table 1. *The possibilities that people envisage for "if" and "if and only if" according to two alternative theories*

	A & B	*not-A & not-B*	*not-A & B*	*A & not-B*
True possibilities				
If A, B	+	+	+	−
If and only if A, B	+	+	−	−
Antecedent possibilities				
If A, B	+	−	−	+
If and only if A, B	+	−	+	+

Note: Key: a "+" indicates that the theory proposes that this possibility is envisaged; a "−" indicates that it is not.

EXPERIMENT 1: CONJUNCTIONS PRIME TRUE POSSIBILITIES FOR CONDITIONALS AND BICONDITIONALS

The aim of the first experiment was to examine conjunctions—for example, "there are apples and there are oranges" (A and B)—as primes for understanding conditionals—for example, "if there are apples then there are oranges"—and biconditionals—for example, "if and only if there are apples then there are oranges". The logic of this procedure is that when people have in mind a possibility it will be easier to process an assertion that corresponds to it. We compared affirmative conjunctions and negated-antecedent conjunctions.

The model theory predicts that a conditional will be primed equally by an affirmative conjunction and a negated-antecedent conjunction: Both are true possibilities, and so no differences in reading times for the conditional should be observed when the two primes are compared. It predicts that a biconditional will be primed by the affirmative conjunction but not by the negated-antecedent conjunction: Only the former is a true possibility for the biconditional. A difference in reading times for the biconditional should be observed, in that it should be read faster when it is primed by the affirmative conjunction than when it is primed by the negated-antecedent conjunction. We derive the opposite prediction from the suppositional theory. It predicts no difference in reading times for the biconditional, whether it is primed by an affirmative conjunction or the negated-antecedent conjunction, and a difference in reading times for the conditional, in that it should be read faster when it is primed by the affirmative conjunction than when it is primed by the negated-antecedent conjunction.

Method

Design and materials

We constructed scenarios that contained seven sentences (or sentence fragments) presented one by one: two scene-setting sentences—for example, "Carmen went shopping to the market. When Carmen looked at the shelves she saw that"—followed by the key conjunction—for example, "there were apples and there were oranges". Another scene-setting sentence, "When she looked at the poster she saw written there", was followed by the conditional—for example, "if there are apples then there are oranges"—and a final scene-setting sentence "Carmen checked her list of purchases". The scenarios were followed by a simple comprehension question, such as "Did Carmen go shopping to the market?" The participants were not required to make propositional inferences, and the simple questions were designed to ensure that they read the stories for comprehension. Half of the questions required an affirmative response, and the other half required a negative response, and they targeted information presented at the start, middle, and end of the stories to ensure that participants read each story. The stories were presented to the participants in their native Spanish.

The first independent variable was the type of conjunction: affirmative conjunctions—for example "there were apples and there were oranges"—and negated-antecedent conjunctions—for example, "there were no apples and there were oranges". The second independent variable was the type of connective: Half of the scenarios were based on conditionals—for example, "if there are apples then there are oranges"—and the other half were based on biconditionals—for example, "if and only if there are apples then there are oranges". The target measures were the reading times for the conditional or biconditional. The design was fully within participants, and participants received 12 instances of the four experimental conditions (2 conditionals by 2 conjunctions), making a total of 48 trials. Each individual participant was given the 48 trials with a different content assigned at random—that is, 48 distinct contents. There were also 32 filler paragraphs in which no propositional connectives appeared (using 32 different contents). We gave each participant the 80 trials in a different random order.

Participants and procedure

The participants were 32 students at the University of La Laguna, who received course

credit for their participation. They were tested individually in a quiet room, and the experiment was controlled online by an IBM-compatible computer, running APT PC software (Poltrock & Foltz, 1988). They were encouraged to read the scenarios carefully at their own pace and to answer the questions as quickly and accurately as possible. The seven sentences in a scenario for each trial were presented one sentence at a time. After reading each sentence, the participants had to press the space bar to erase the screen and display the next sentence. After reading the question, the participants responded "yes" by pressing the right-hand key or "no" by pressing the left-hand key. The computer recorded participants' reading times for the conjunctions and the conditionals. Participants were given six practice scenarios presented before the experimental set to familiarize them with the procedure. Four of the scenarios matched the structure of the experimental trials, and two were similar to the fillers. The instructions given to the participants were as follows:

> "The purpose of the experiment that you will be doing is to study what psychological processes are implicated in text comprehension. Your task will consist of reading stories quickly and accurately. When you finish reading a sentence and are ready to read the next sentence, please press the space bar. After reading each story, you must answer a question concerning a different part of the story."

Results and discussion

Table 2 shows the reading time for the two connectives (conditional and biconditional) after reading the conjunctions (A and B, and not-A and B). Before any data analysis, we identified outliers as any latency that was less than the mean latency divided by two or greater than the mean latency plus 2.5 standard deviations. These outliers were replaced by the mean latency divided by two, or the mean latency plus 2.5 standard deviations, respectively. Total outliers replaced comprised 3% of the data set. Only participants who had more than 85% correct responses to the simple questions were included in the analysis, and only the reading times corresponding to their correct responses were analysed.

Table 2. *The reading times for the two connectives after participants read the two sorts of conjunctions in Experiment 1*

Target connective	*Conditional*	*Biconditional*
Affirmative conjunction prime	1,594 (267)	2,211 (482)
Negated-antecedent conjunction prime	1,608 (302)	2,371 (556)
Difference	−14	−160

Note: Reading times in ms. Standard deviations in parentheses.

We carried out a 2 (conditional vs. biconditional) by 2 (affirmative conjunction vs. negated-antecedent conjunction) analysis of variance (ANOVA) with repeated measures on both factors. It showed a main effect of connective, reflecting that participants took 690 ms longer to read a biconditional than a conditional after the conjunctions, $F(1, 31) = 175.29$, $MSE = 86{,}835$, $p < .0001$. It also showed a main effect of conjunction, reflecting that participants took 174 ms longer to read a connective after reading a negated-antecedent conjunction than an affirmative conjunction, $F(1, 31) = 7.21$, $MSE = 33{,}479$, $p < .02$. The interaction was reliable, $F(1, 31) = 5.49$, $MSE = 30{,}996$, $p < .03$, showing that the participants took 160 ms longer to read a biconditional after they had read a negated-antecedent conjunction than an affirmative conjunction, $F(1, 31) = 7.68$, $MSE = 53{,}139$, $p < .01$. There was no reliable difference in the length of time it took to read a conditional after participants had read a negated-antecedent conjunction or an affirmative conjunction (14 ms; $F < 1$).

The experiment shows that people read a biconditional "if and only if A then B" more quickly when they have first read an affirmative conjunction than when they have first read a negated-antecedent conjunction. It also shows that people read a conditional "if A then B" equally quickly whether they have first read an affirmative conjunction or a negated-antecedent

one. The results corroborate the predictions of the model theory (Johnson-Laird & Byrne, 2002). They support the idea that people keep in mind true possibilities. The results go against the predictions of the suppositional theory that people think about possibilities that contain the antecedents of assertions. In our next experiment we test whether the conditional and biconditional prime the true possibilities but not the false possibilities. Once again we pit the predictions of the two theories against one another.

EXPERIMENT 2: CONDITIONALS AND BICONDITIONALS PRIME TRUE POSSIBILITIES

The aim of the second experiment was to examine biconditionals and conditionals as primes for understanding conjunctions.

The predictions derived from the model theory are that people will read an affirmative conjunction—for example, "there were apples and there were oranges"—equally quickly whether they are primed by a biconditional or a conditional: The conjunction is a true possibility for both connectives. They will read a negated-antecedent conjunction—for example, "there were no apples and there were oranges"—more quickly when they are primed by a conditional than when they are primed by a biconditional: The conjunction is a true possibility for a conditional but not for a biconditional. Once again, the predictions derived from the suppositional theory are the opposite: People will read the negated-antecedent conjunction (not-A and B) more quickly when they are primed by a biconditional than when they are primed by a conditional: The conjunction contains an antecedent possibility for a biconditional (on its "if A then B and if B then A" interpretation) but not for a conditional.

Method

Design, materials, and procedure

The materials were the same as those used in Experiment 1 except that the conditional or biconditional premise was presented before the conjunctions. The design and procedure were identical to those in Experiment 1.

Participants

The participants were a new set of 32 students from the University of La Laguna, who received course credit for their participation.

Results and discussion

Table 3 shows the reading time for the two conjunctions (A and B, and not-A and B) after reading the connectives (conditional and biconditional). We treated outliers in the same way as in the previous experiment, and the total outliers replaced was 3%. We carried out a 2 (conditional vs. biconditional) by 2 (affirmative vs. negated-antecedent conjunction) ANOVA with repeated measures on both factors. The ANOVA showed a main effect of conditional, reflecting that participants took 149 ms longer to read a conjunction after they had first read a biconditional than after they had first read a conditional, $F(1, 31) = 9.17$, $MSE = 77{,}791$, $p < .005$. It also showed a main effect of conjunction, reflecting that the participants took 557 ms longer to read the negated-antecedent conjunctions than the affirmative conjunctions, $F(1, 31) = 90.48$, $MSE = 109{,}421$, $p < .0001$. The interaction was reliable, $F(1, 31) = 5.62$, $MSE = 72{,}735$, $p < .025$, showing that the participants took 262 ms longer to read a negated-antecedent conjunction after they had first read a biconditional than after they had first read a conditional, $F(1, 31) = 8.54$, $MSE = 128{,}912$, $p < .006$. There were no reliable

Table 3. *The reading times for the two conjunctions after participants read the conditional and the biconditional in Experiment 2*

Target conjunction	*Affirmative*	*Negated antecedent*
Conditional prime	1,451 (282)	1,894 (382)
Biconditional prime	1,487 (275)	2,157 (701)
Difference	−36	−263

Note: Reading times in ms. Standard deviations in parentheses.

differences for affirmative conjunctions (36 ms; $F < 1$).

The experiment shows that a conditional "if A then B" primes reading "A and B" and "not-A and B". A biconditional "if and only if A then B" primes reading the affirmative conjunction but not the negated-antecedent one. The results corroborate the predictions of the model theory: The conditional primes both its true possibilities; the biconditional primes its true possibility and not its false possibility. Once again the results go against the predictions of the suppositional theory.

GENERAL DISCUSSION

An affirmative conjunction primes reading a conditional and a biconditional; a negated-antecedent conjunction primes reading a conditional but not a biconditional, as the first experiment shows. A conditional primes reading an affirmative and a negated-antecedent conjunction; a biconditional primes reading an affirmative but not a negated-antecedent conjunction, as the second experiment shows. The results show that (a) people think about the true possibilities, "A and B", and "not-A and B", when they understand a conditional "if A then B"; (b) they think about the true possibility "A and B", and they do not think about the false possibility "not-A and B", when they understand a biconditional "if and only if A then B". Both experiments corroborate the predictions of the model theory: People think about true possibilities, they do not envisage false possibilities (Johnson-Laird & Byrne, 2002).

The results go against the predictions that we derived from the suppositional theory, which proposes that people think about possibilities that contain the antecedent of the assertion (Evans et al., 2005). They may also be difficult to explain for theories of formal rules of inference (Braine & O'Brien, 1998; Rips, 1994) and theories based on domain-specific rules of inference (Fiddick, Cosmides, & Tooby, 2000; Gigerenzer & Hug, 1992; Holyoak & Cheng, 1995). These theories do not provide the means by which predictions can be derived about whether certain conjunctions should be primed by conditionals, and other conjunctions should not. The results support the idea that people think about what is true, not what is false. This idea has widespread consequences for how people think and reason in many domains.

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