Universal Connectives in the Selection Task

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Two experiments using Wason’s selection task are reported in this paper. Their main purpose was to test the meaning of universal connectives (always and never) against the hypothetical conditional connective (if). In the first experiment, these two different kinds of connectives were used with the same content and in logically equivalent situations. Results demonstrated that universal connectives yield different patterns of responses than do hypothetical connectives. People seem to consider the situation described in the task in the same way, irrespective of the use of negations, when universal connectives are used, but not when the if...then structure is used. The second experiment extended these results to a different content, and to an abstract version of the task. An explanation in terms of mental models is provided.

One of the most widely used paradigms in the study of human reasoning during the last quarter of the century is the four-card problem or Wason’s selection task. In the first version (Wason, 1966), a set of cards was used. Each of these cards showed a number on one side and a letter on the other. When four of these cards were placed on the table, the subject could see one of the sides of each card, and the other side remained hidden. On the visible sides of the four cards, subjects found two numbers (4 and 7) and two letters (E and D). The task was to decide which cards would need to be turned over in order to find out whether the following conditional rule was true or false: “If there is an E on one side of the card, then there is a 4 on the other side.” According to the truth table of single conditional, the card “E” (p) should be turned over to check whether there is a “4” (q) on the other side; if there is not, then the rule is false. The rule cannot be disproved by checking the reverse side of the “D” (¬p) or “4” (¬q) cards (the symbol “¬” represents negation). However, it is necessary to verify the hidden side of the card “7” (¬q), to test whether there is an “E” (p) on the other side, because in that case the rule would be false.
In spite of the logical simplicity of the problem, great psychological difficulty has been found with this task. Most subjects select card combinations other than “p and ¬q”. The most common responses are “p and q” or only “p” (see Evans 1982, 1989). These results cannot be explained by a misinterpretation of the conditional as a bi-conditional or conjunction, because this would lead to a selection of the four cards, and this is a very unusual response. These results were originally interpreted as a “confirmation bias” (Wason, 1966)—that is to say, subjects try to find evidence confirming the rule rather than evidence falsifying it. Evans (1972; also Evans & Lynch, 1973) proposed an alternative explanation in terms of a “matching bias”, which supposes that subjects select the cards named in the rule. This interpretation can explain the results in the traditional version of the selection task and fits very well with negated versions. For example, given the rule: “If there is an E on one side of the card, then there is not a 4 on the other side”, subjects would correctly select the “E” and “4” cards, and not “E” and “7”, as predicted by the verification hypothesis.

Evans (1984, 1989) explains the matching bias in terms of the perceived relevance of the cards. This relevance depends on two heuristics. The first, the if-heuristic, leads subjects to select those cards that make the antecedent true; consequently, subjects would prefer the true antecedent card over the false one. The second mechanism is the not-heuristic, by means of which subjects consider negation as a mere comment on the proposition, and therefore the original (affirmative) proposition remains the topic of the task.

In the mental-model theory of reasoning (see Johnson-Laird & Byrne, 1991), in order to solve the selection task, the subjects produce a set of models representing the state of affairs to which the task is referred and select “those cards for which the hidden value could have a bearing on the truth or falsity of the rule” (Johnson-Laird & Byrne, 1991, p. 79). The statement “If there is an E on one side of the card, then there is a 4 on the other side” elicits the models:

\[
\begin{array}{cc}
[E] & 4 \\
\ldots \\
\end{array}
\]

where, according to the Johnson-Laird and Byrne notational system, the square brackets mean that the set is exhausted (elements should not occur anywhere else in the models), and the dotted line means that there are implicit models. Given this representation, subjects would select only the “E” card. The rule could also be interpreted as a bi-conditional:

\[
\begin{array}{cc}
\ldots \\
\end{array}
\]

where both sets are exhausted and subjects would tend to select both “E” and “4”. Consequently, according to the theory, the poor performance of the subjects in this task is due to their tendency to consider only the initial models to produce the conclusion. However, models could be “fleshed out” to represent all the relevant cases. For a single-conditional interpretation, these cases would be:
so that the card corresponding to the false consequent is associated only with “$\neg E$” because “E” was exhausted in the initial model. The correct solution would depend on the representation of the impossible relation between “E” and “$\neg 4$” according to the rule. Thus, if subjects grasp that a card with an “E” on one side (either the visible or the invisible side) cannot have a “$\neg 4$” on the other side, they would select the not-$q$ card. The inclusion of negations in either the antecedent or the consequent yields the models, including the corresponding affirmative items. Johnson-Laird and Byrne (1991, p. 80) even suggest that some individuals may represent the assertion as a disjunction of two positive instances:

$$E \quad 4$$

$$\neg E \quad 4$$

$$\neg E \quad \neg 4$$

Thus, the predicted pattern of selections is the same as in the affirmative version of the rule. The representation of a conditional with a negative consequent, such as: “If there is an E on one side of the card, then there is not a 4 on the other side” includes the initial models (if taken as a single-conditional):

$$[E] \quad \neg 4$$

$$4$$

$$\ldots$$

Although the effects of negations and “matching” are appropriately explained within this theory—subjects focus on the cards in their explicit models of the conditional and select those that are relevant to its truth or falsity—Evans (1993) has argued that the model theory needs some reformulation to account for several phenomena of conditional reasoning. One of the core points of this proposal is that although the model theory predicts affirmative inferences to be more frequent than negative ones (because the affirmative items are always in the initial models), the frequency of affirmation of the consequent and denial of the antecedent is about equal in several studies. Evans (1993) proposes the existence of a “negative conclusion bias” to account for these results. Schaeken, García-Madruga, and Johnson-Laird (1995) have recently tested the model theory for conditionals with negative constituents. Their findings favour the (standard) model theory and reject the negative conclusion bias.

A prediction made by the mental-model theory that could not be endorsed by the matching-bias-heuristic account is that different connectives would lead to different selections in the selection task. Such differences have been reported by Wason and Green (1984) using quantifiers instead of conditional connectives. In this paper we explore “always” and “never” in combination with “with” and “without”. These universal connectives yield an explicit representation of the relationship between the antecedent and the consequent of the rule (they are not hypothetical, as is the conditional if).
For the mental model theory, the main point determining the representation of a given statement is the subject’s understanding of the state of affairs described in the statement, not its superficial structure. For the statements: “He always drinks coffee with sugar” (Plain $p \rightarrow q$), and “He never drinks coffee without sugar” (Reverse $p \mapsto \neg q$), the state of affairs described is clearly the same, and consequently the same models would be built. However, although the statements: “If he drinks coffee, then he has sugar” (Plain $p \rightarrow q$), and “If he doesn’t have sugar, then he doesn’t drink coffee” (Reverse $p \mapsto \neg q$), are also logically equivalent, the subject’s interpretation of the state of affairs could change and the models include different tokens. Similarly, while the statements “He always drinks coffee without sugar” (Plain $p \mapsto \neg q$) and “He never drinks coffee with sugar” (Reverse $p \rightarrow q$) produce the same interpretation, the logically equivalent “If he drinks coffee, then he doesn’t have sugar” (Plain $p \rightarrow \neg q$) and “If he has sugar, then he doesn’t drink coffee” (Reverse $p \mapsto \neg q$), yield different interpretations. Table 1 includes the mental model representations for each of the above statements, combining both types of connectives (hypothetical and universal) and the four rules (Plain $p \rightarrow q$, Reverse $p \mapsto q$, Plain $p \mapsto \neg q$, and Reverse $p \rightarrow \neg q$). Note in the table that for the universal connectives the representation is the same for the logically equivalent rules.

According to the model theory, two predictions could be made: First, the cards corresponding to the tokens in the explicit models should be selected more frequently than cards corresponding to those not present in the models. Second, there should be a directional bias while processing the models; thus, the cards corresponding to the first of the explicit models (when there is more than one model) should be selected more frequently than those of the second model, and the first term in the first model should yield the maximum selection of its corresponding card. Therefore, the logically equivalent rules should lead to the same patterns of selection with the universal connectives and not with the hypothetical connectives. These concrete predictions about card selection frequencies are also present in Table 1.

Two experiments are reported in this paper to test these hypotheses. The coffee and sugar content in the examples above was used in Experiment 1, and Experiment 2 compares a different thematic content with an abstract version of the task.

**EXPERIMENT 1**

For this experiment we constructed four experimental conditions, two pairs of logically equivalent propositions (If $p$ then $q$ is logically equivalent to If $\neg q$ then $\neg p$; and If $p$ then $\neg q$ is logically equivalent to If $q$ then $\neg p$). Two types of connectives were also used. With the traditional If . . . then formulation, different patterns of responses were expected for the logically equivalent conditions, whereas with the universal Always/never the same pattern was expected for the equivalent conditions because the state of affairs described was clearly the same.
Method

Subjects

Sixty-two Introductory Psychology students of the Universidad Autónoma de Madrid (50 females and 12 males) served as subjects. They were randomly assigned to two equal groups, so that half of them solved selection tasks of the \( \text{if} \ldots \text{then} \) form and the other half those with the always/never connectives.

Design

A \( 2 \times 2 \times 2 \) factorial design was used. Two of these factors were within-subjects and one was between subjects. The first within-subjects factor was the logical meaning of the form, and its two levels were affirmative implication (\( \text{if} \ p \ \text{then} \ q \) or equivalent) and negative implication (\( \text{if} \ p \ \text{then} \ \neg q \) or equivalent). The second within-subjects factor was the syntactic order of the elements in the rule (plain or reverse). For the same level of the logical factor, the two levels of this second factor were logically equivalent; for this purpose, we used negation combined with the reverse order. That is to say, the reverse of \( \text{if} \ p \ \text{then} \ q \) was \( \text{if} \ \neg q \ \text{then} \ \neg p \) and the reverse of \( \text{if} \ p \ \text{then} \ \neg q \) was \( \text{if} \ q \ \text{then} \ \neg p \). The between-subjects factor was the connective—hypothetical or universal—used.

### TABLE 1
Initial Mental Model Representations and Predicted Selection Trends for Each of the Rules with Each Connective

<table>
<thead>
<tr>
<th>Connective</th>
<th>Hypothetical</th>
<th>Universal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule</td>
<td>Models</td>
<td>Predictions</td>
</tr>
<tr>
<td>c→s Plain</td>
<td>[c] s</td>
<td>c &gt; s &gt; (¬c, ¬s)</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Reverse</td>
<td>[¬s] ¬c s c</td>
<td>[TA &gt; TC &gt; (FA, FC)]</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>c→¬s Plain</td>
<td>[c] ¬s s c</td>
<td>[TA &gt; TC &gt; FC &gt; FA]</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Reverse</td>
<td>[s] ¬c s c</td>
<td>[TA &gt; TC &gt; FC &gt; FA]</td>
</tr>
<tr>
<td></td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

Note: “>” = “predicted to be more frequently selected than”; “¬” = “negation”. No difference is predicted for terms in parentheses, separated by a comma. The expressions in square brackets translate the predictions to the general notation of true antecedent (TA), true consequent (TC), false antecedent (FA), and false consequent (FC) that is used in the experiments.
Materials and Procedure

Subjects were tested in their original classrooms, where they received general instructions on the selection task. They were then given a booklet in which the first page (the same for all subjects) informed them that a young waiter was trying to learn the coffee-drinking habits of four customers. Subjects were asked to suppose that the young waiter was not sure whether an old waiter had told him the truth about the customers’ habits. Thus he needed to test the truth or falsity of the rules provided by the old waiter using some notes on one side of which the old waiter had recorded whether a customer had drunk coffee and on the other side whether they had used sugar. On each of the following four pages of the booklet there was a rule and four rectangles intended to represent notes made by the old waiter about one of the customers. The rectangles contained, in random order, the legends “coffee”, “sugar”, “no coffee”, and “no sugar”. On each page, the subject was asked to indicate which notes needed to be turned over to test the rule. The order of the pages, and of legends within pages, was randomized.

The eight rules used were the following:

Hypothetical

Plain “p→q” “If he drinks coffee, then he has sugar.”
Reverse “p→q” “If he doesn’t have sugar, then he doesn’t drink coffee.”
Plain “p→¬q” “If he drinks coffee, then he doesn’t have sugar.”
Reverse “p→¬q” “If he has sugar, then he doesn’t drink coffee.”

Universal

Plain “p→q” “He always drinks his coffee with sugar.”
Reverse “p→q” “He never drinks his coffee without sugar.”
Plain “p→¬q” “He always drinks his coffee without sugar.”
Reverse “p→¬q” “He never drinks his coffee with sugar.”

Results

A general index was computed for the analysis. The index was similar to the logic and matching indices used by Pollard and Evans (1987). As the hypotheses were not referred to logical validity or matching bias, the logic or matching indices were not used in this case. Instead, we used a kind of verification index: We scored +1 when a card representing an instance that appeared in the rule was selected (with the same affirmative or negative status) and −1 when the selected card had the opposite status to the concept in the rule (i.e. when it was affirmed in the rule and negated on the selected card, or negated in the rule and affirmed on the card). Thus, the scores were positive for the true antecedent and true consequent instances (TA and TC, in the terms of Evans, 1989). The rank of the resulting score was the same as that of the logic and matching indices (a five-point scale from −2 to +2). We will call this measure, “adjustment to the rule” (AR), and the mean scores for each of the experimental conditions are reported in Table 2. An analysis of variance (ANOVA) was performed on the AR scores. The connective used produced a reliable effect, $F(1, 60) = 75.00, p < .0001$, in the sense that the hypothetical connective yielded more adjustment than the universal connectives. There was no significant effect of the logic structure but a clearly reliable effect of the syntactic order, $F(1, 60) = 131.01,$
that is, reverse syntax produced less AR, regardless of the logical structure of the rule. The only significant interaction was Connective Used × Syntactic Order, $F(1, 60) = 75.43, p < .0001$. Thus the reverse syntax scored lower when the universal connectives were used.

Table 3 shows the selection percentages for each of the cases, True Antecedent (TA), True Consequent (TC), False Antecedent (FA), and False Consequent (FC), in each condition. TA and TC were selected by most subjects in all the conditions except the reverse order with universal connectives, where the majority of the subjects selected FA and FC. Note that the cases selected in the universal-connectives conditions corresponded to the cards: coffee and sugar, for the $p\rightarrow q$ rules (either plain or reverse), and coffee and not-sugar for the $p\rightarrow \neg q$ rules. With the hypothetical connectives, the most frequently selected cards were coffee and sugar in the plain-order $p\rightarrow q$ condition, not-coffee and not-sugar in the reverse order $p\rightarrow q$ condition, coffee and not-sugar in the plain $p\rightarrow \neg q$ condition, and sugar and not-coffee in the reverse $p\rightarrow \neg q$ condition. Thus, the pattern of selection is similar for the logically equivalent conditions when the connective is universal, but different in the hypothetical-connective conditions, where the more frequently selected cards are those mentioned in the rule with the same status (affirmative or negative).

Page’s $L$ test was used to confirm the predicted trends (see Table 1). These hypotheses were all confirmed. TA was selected more frequently than TC and TC more frequently than either FA or FC in $p\rightarrow q$ plain problems, both hypothetical and universal ($L = 407, z = 4.45, p < .0001$; and $L = 411, z = 4.95, p < .0001$, respectively). The same pattern was confirmed for the hypothetical $p\rightarrow q$ reverse condition ($L = 389, z = 2.16, p < .02$), and universal $p\rightarrow \neg q$ plain ($L = 413, z = 5.21, p < .0001$). The trend FA > FC > (TA, TC) was confirmed in universal reverse $p\rightarrow q$ and $p\rightarrow \neg q$ ($L = 415, z = 5.46, p < .0001$; and $L = 408, z = 4.51, p < .0001$, respectively). The hypothetical $p\rightarrow \neg q$ rules produced explicit models of the affirmed consequent and not of the affirmed antecedent (see Table 1). Thus, the trend for these problems comprises four levels ordered: TA > TC > FC >
This pattern was confirmed for both plain ($L = 865, z = 5.60, p < .0001$) and reverse ($L = 858, z = 5.16, p < .0001$) versions of those rules.

**Discussion**

The predicted effect of the connective used was found in this experiment. Moreover, this effect was demonstrated to be independent of logical validity. As the predicted patterns are not logically correct for any of the conditions, the effect is not a mere *facilitation*, but a difference in the reasoning process. As mentioned earlier, this difference can be explained by the model theory and not by the matching bias/heuristic account. Obviously, the cards mentioned in the rule are the same for the hypothetical and universal conditions, so that no differences could be predicted by matching. When always/never were the connectives, the state of affairs encoded by the subjects (their mental model) was the same for the equivalent conditions. If someone says that he or she “always has coffee with sugar”, then that person is clearly saying the same thing as one who says that he or she “never has coffee without sugar” (provided that in both situations that person drinks coffee, as was made clear by the context of the task). Note that the responses given in these cases are not correct more frequently than in the *if . . . then* situations, but closer for equivalent conditions, and this suggests a similar interpretation. In the hypothetical problems, the responses are closer to a superficial representation of the problem.

All the predicted trends were confirmed in this experiment. These results suggest that the predicted representations of both hypothetical and universal connectives are correct. The meaning of the universal connectives prevented the inclusion of additional explicit models reducing the selection rate of the residual cases (i.e. those absent from the rule and not explicitly represented in the models). An alternative explanation of the results of this experiment could be based upon the interaction of the content used and the kind of connective. This possibility is tested in Experiment 2.
EXPERIMENT 2

The predictions of the model theory were confirmed in Experiment 1. However, the use of a familiar context in this experiment prevented the isolation of the factor explaining the effects attributed to the connectives. They might be an effect of the connective itself or result from an interaction between the connective and the content. In this second experiment we used a different thematic content together with abstract conditions to test the relation between connectives and context.

Method

Subjects

One hundred education students from the “Universidad de La Laguna” (of whom 82 were females) served as subjects. As in the first experiment, they had had no previous experience with the selection task.

Materials and Procedure

The procedure was the same as that in Experiment 1. The materials matched the logical and syntactical manipulations introduced in the first experiment, but a content factor was added, with two levels: thematic and abstract. The thematic materials used were also different from those in Experiment 1: In the thematic conditions, subjects received instructions concerning a company in which pairs of employees who work on different shifts share a parking place. The employees can use a car or a motorcycle to go to work. Subjects were told: “On one side of the cards you can find the name of the employee on duty in a given moment, and in the other side, the vehicle that is on the corresponding parking place. [. . . ] Your job is to decide what card or cards need to be turned over in order to find out if the rule is true or false.”

The eight rules used in the thematic conditions were the following:

Hypothetical

Plain “p→q” “If Marta came, then there is a car.”
Reverse “p→q” “If there isn’t a car, then María didn’t come.”
Plain “p→¬q” “If Petra came, then there isn’t a car.”
Reverse “p→¬q” “If there is a car, then Carmen didn’t come.”

Universal

Plain “p→q” “Marta always came with a car.”
Reverse “p→q” “María never came without a car.”
Plain “p→¬q” “Petra always came without a car.”
Plain “p→¬q” “Carmen never came with a car.”

The abstract conditions used letters and numbers:
**Hypothetical**

Plain “\( p \rightarrow q \)”

“If an A has been placed on one side, then a 4 has been placed on the other side.”

Reverse “\( p \rightarrow q \)”

“If a 4 hasn’t been placed on one side, then an A hasn’t been placed on the other side.”

Plain “\( p \rightarrow \neg q \)”

“If an A has been placed on one side, then a 4 hasn’t been placed on the other side.”

Reverse “\( p \rightarrow \neg q \)”

“If a 4 has been placed on one side, then an A hasn’t been placed on the other side.”

**Universal**

Plain “\( p \rightarrow q \)”

“A’s have always been placed with a 4 on the other side.”

Reverse “\( p \rightarrow q \)”

“A’s have never been placed without a 4 on the other side.”

Plain “\( p \rightarrow \neg q \)”

“A’s have always been placed without a 4 on the other side.”

Reverse “\( p \rightarrow \neg q \)”

“A’s have never been placed with a 4 on the other side.”

Twenty-five subjects were randomly assigned to each of the four between-subjects conditions (hypothetical–abstract, hypothetical–thematic, universal–abstract, or universal–thematic), so that each subject solved four problems.

**Results**

As in the first experiment, the AR index was computed. The mean scores for this index in each of the conditions are reported in Table 4. The new variable introduced in this second experiment, the abstract or thematic content, produced no reliable effects. As in the first experiment, the connective used yielded a reliable effect: AR was larger with the hypothetical connectives, \( F(1, 96) = 51.03, p < .0001 \). Again there was no effect of the logical structure, but there was a reliable effect of the syntactic order, \( F(1, 96) = 59.45, p < .0001 \) (reverse syntax produced less AR, regardless of the logical structure of the rule). An

<table>
<thead>
<tr>
<th>Connective</th>
<th>Logical Structure</th>
<th>Order</th>
<th>Abstract</th>
<th>Thematic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothetical</td>
<td>( p \rightarrow q )</td>
<td>Plain</td>
<td>1.28</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reverse</td>
<td>0.92</td>
<td>0.32</td>
</tr>
<tr>
<td></td>
<td>( p \rightarrow \neg q )</td>
<td>Plain</td>
<td>0.68</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reverse</td>
<td>0.64</td>
<td>0.80</td>
</tr>
<tr>
<td>Universal</td>
<td>( p \rightarrow q )</td>
<td>Plain</td>
<td>1.44</td>
<td>1.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reverse</td>
<td>−1.32</td>
<td>−1.12</td>
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<td>( p \rightarrow \neg q )</td>
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<td>0.80</td>
<td>0.96</td>
</tr>
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<td></td>
<td></td>
<td>Reverse</td>
<td>−0.96</td>
<td>−1.12</td>
</tr>
</tbody>
</table>

*Note: Experiment 2: \( n = 25 \) per group.*
interaction of connective used with syntactic structure was found as in the first experiment, $F(1, 96) = 36.38, p < .0001$. Therefore, the reverse syntax produced less AR only if the connective used was always/never. In this experiment we also found an interaction (not significant in the first experiment) between the logical structure and the syntactic order of the problem, $F(1, 96) = 9.79, p < .005$. This interaction reveals a greater difference between plain and reverse order when the logical structure is “$p \rightarrow q$”.

Table 5 presents the selection percentages for each card across the experimental conditions. The results matched those found in the first experiment. The $z$ scores from the Page tests performed on the same hypotheses tested in Experiment 1 are also shown in Table 5. Most of these contrasts were significant, both for thematic and abstract problems. The only non-reliable test—although the percentages differ in the right direction—was that performed on the thematic reverse “$p \rightarrow q$” condition with the hypothetical connective.

**Discussion**

This experiment has reproduced the findings reported in Experiment 1 with a different thematic content and with an abstract content. Consequently, the effects should be attributed to the semantics of the universal connectives as compared to those of the hypothetical connectives. As mentioned, this phenomenon is consistent with the model theory of reasoning. A possible interaction between content and connective, which remained an alternative explanation for the results in the first experiment, can be rejected.

The only unpredicted result in this experiment is the lack of reliability found in the thematic reverse “$p \rightarrow q$” condition with the hypothetical connective. It should be noted

<table>
<thead>
<tr>
<th>Rule</th>
<th>Abstract</th>
<th>Thematic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Plain</td>
<td>Rev.</td>
</tr>
<tr>
<td>Hypothetical</td>
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<tr>
<td>TA</td>
<td></td>
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<tr>
<td>TC</td>
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<td></td>
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<tr>
<td>FA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FC</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PT (z)*</td>
<td>3.39</td>
<td>2.70</td>
</tr>
<tr>
<td>Universal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TC</td>
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</tr>
<tr>
<td>PT (z)*</td>
<td>4.03</td>
<td>3.18</td>
</tr>
</tbody>
</table>

* $z$ scores greater than 1.65 are reliable at $p < .05$ level.

**Note:** Experiment 2: $n = 25$ per group.
that in Experiment 1 this was the condition in which the Page test showed the weakest effect. The reason may be the added difficulty of a rule that includes two negations. This could overload subjects’ working memory, producing the smallest $z$ values in the hypothetical reverse “$p\rightarrow q$” conditions. As well as the difficulty of the task possibly producing random responses, in this condition the models represent all the four terms (see Table 1 above), so the differences predicted among them are smaller than in the situations in which some of the terms are not represented.

**GENERAL DISCUSSION**

We have shown in this paper that the use of universal connectives instead of the usual hypothetical connectives yields different response patterns in the selection task. These patterns are those predicted by the model theory of reasoning. Mental models are unitary representations of the state of affairs described in the problem. When subjects imagine the same states of affairs, they build the same models. Logically equivalent problems are supposed to produce the same models only if subjects understand them as describing the same situation. What determines the conclusion given is the representation produced, not the logical status of the problem. The logically equivalent problems used in this investigation produced the same representation with universal connectives, and they did not do so with hypothetical connectives. Subjects gave the same responses to logically equivalent problems when universal connectives were used; they did not when the problems included hypothetical connectives. Consequently, the situation as it was understood was the main determinant of performance and not the logical status of the problem.

In Experiment 1 a familiar content was used. The use of negative universal connectives sounds natural within this context. It could be argued that the findings of this experiment are due to the circumstance that the statements that included universal connectives were more natural than those that included hypothetical connectives. However, in Experiment 2 the same results were found using a different content and context, and even in an abstract situation. In our opinion, the semantics of universal connectives are responsible for these results. Universal connectives accommodate negation more easily than do hypothetical connectives. Indeed, most, if not all, of the major languages contain different words for “always” and “never” (so that there is no need to say “always not”); and for “with” and “without” (so that it is not necessary to say “with no”). Thus, “always–with” is understood in the same way as “never–without”, and “always–without” describes the same state of affairs as “never–with”. This identification occurs as a result of the initial representation of the problem, so that subjects select the same cards even if they do not flesh out the models. With the hypothetical connectives, subjects would produce the same pattern in the logically equivalent conditions only if they fully fleshed out the models. In this case, it should be the correct pattern.

The main feature of the selection task for the investigation of mental models is that its solution frequently depends on the initial representation. A conditional truth-table task could force subjects to flesh out models to answer all of the four questions (i.e. MP, MT, AC, and DA). Initial representations are therefore difficult to study from this paradigm. On the contrary, the selection task uses a general question involving all the four inferences, so most subjects solve the task using the initial representation. Although the
Selection task is one of the more widely used paradigms in the study of thematic effects, the results obtained from this task are difficult to explain in terms of believability. In most experiments it is not possible to think that some cards are more believable than others, so the mechanisms created to explain thematic effects in syllogistic reasoning, such as selective scrutiny or misinterpreted necessity (Barston, 1986; Evans, 1989), cannot be applied. The matching bias account is also inappropriate, because it cannot predict different results when the same propositions are used and the only change is the kind of conditional connective. Matching bias is not a universal finding; it occurs in conditional reasoning but not in disjunctive reasoning (Evans & Newstead, 1980). Evans (1989) considers matching to be a consequence of the perceived relevance of the statements. Consequently, the presence of matching in conditionals is due to their hypothetical nature: Subjects can consider three truth values (true, false, and irrelevant). In our universal conditions, conditionals could lose their hypothetical sense, and this may explain the lack of matching found. However, according to the heuristic/analytic approach, this would increase the number of correct responses, and this did not occur. For the heuristic approach, the only way to explain the data is to propose a post hoc “always-heuristic”, which would limit the parsimony and the feasibility of the theory.

Current theories of reasoning based on formal rules of inference (Braine, 1990; Braine & O’Brien, 1991; Rips, 1983, 1994) contain no specific mechanism equivalent to the initial representation in mental model theory. According to Rips’s (1994) theory, the selection task is solved by the application of a single rule to four pairs of premises. Each of these pairs is made up of a conditional statement and a categorical premise containing the meaning of the visible legend of a card. The single rule is the “forward if elimination” rule, which is equivalent to modus ponens. This rule builds a proof only in the TA case. However, if subjects interpret the statement as a bi-conditional, they might select TA and TC. Successful performance depends on the subjects’ ability to consider the hidden values in the cards as potential conclusions for the arguments. This permits them to trigger backward rules (from the conclusion to the premises). The way Braine’s (1990) theory works is quite similar for the selection task. Theories of reasoning by formal rules of inference need a particular set of rules or inference schemas for each connective. There is no account in these theories for universal connectives. If we apply the rules created for the “if” connective to our universal connective conditions, our results cannot be explained: Obviously, no differences are predicted between universal and hypothetical connectives. The need for a particular theory for each linguistic particle is a clear disadvantage of formal-rule theories. The proposal of a unitary semantic representation in the form of a model has the clear advantage of predicting differences among connectives and could even lend itself to other reasoning tasks.

The predictive value of the model theory has been tested in this paper. Although this theory was conceived without considering the results in the selection task with universal connectives, it fitted these data almost perfectly (23 out of 24 Page tests in both experiments confirmed the predicted order of frequencies of card selections). No other current theory of reasoning could explain these data without adjustment, so the predictive power of the model theory has been confirmed.
REFERENCES


*Original manuscript received 11 February 1994
Accepted revision received 17 July 1995*