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# The Spontaneous Use of Propositional Connectives

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We extend the model theory of reasoning to the understanding and use of propositional connectives, such as *and*, *or*, and *if*. We use a novel paraphrase paradigm to compare the model theory to an alternative one based on rules of inference. In Experiment 1, subjects paraphrased pairs of conditionals. Their general knowledge guided their combination of the antecedents: they used disjunctive descriptions to combine antecedents that were each sufficient to bring about the outcome, and they used conjunctive descriptions to combine antecedents that were both necessary to bring about the outcome. They expressed their combinations using simple connectives such as *and* or *or*, as the model theory predicts, rather than hypothetical connectives, such as *and if* or *or if*, as the rule theory predicts. Experiment 2 demonstrated the phenomenon in the less constrained task of combining three assertions in a single conditional. Conjunctions and disjunctions are easy to elicit; conditionals have proved far more difficult. The model theory proposes that individuals represent a conditional situation by keeping in mind the described events, but they also keep in mind that there may be alternatives to the events. Therefore, they should use conditionals when they are aware that the events may or may not occur. Experiment 3 corroborated this prediction: subjects used conditionals to combine assertions (with no restrictions on the connective they should use) when the clause describing the outcome contained a modal verb that suggested that the outcome might or might not occur.

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A complete theory of the propositional connectives *if*, *and*, *or*, and *not* needs to answer three questions: How do people understand them? How do they reason with them? And in what circumstances do they spontaneously use them in descriptions? There are several alternative theories (for reviews see Evans, 1982; Johnson-Laird & Byrne, 1991; Wason & Johnson-Laird, 1972), but they have so far had little to say about the third question. Our aim in this paper is to answer it in the light of a new theory of the connectives.

One view of reasoning is that the mind contains abstract rules of inference (Braine, 1978; Rips, 1983). These rules do not "record truth tables or truth conditions. . . . The inference rules provide instructions about how truth may be inherited from premises to conclusions. . . . No separate 'semantics' . . . is needed" (Braine & O'Brien, 1991, p. 184). When human reasoners are given a disjunction, such as:

*There is a cross or there is a star.*

they access an elementary inference rule such as:

*p or q*
*not p*
*Therefore q*

and so from the additional information:

*There is not a cross.*

they can immediately deduce:

*There is a star.*

A conditional, such as:

*If there is a circle, then there is a triangle.*

is also understood by accessing the appropriate inference rules, of which, according to Braine and O'Brien (1991, p. 183), there are two:

1. Given *if p then q* and *p*, one can infer *q* (Modus ponens).
2. To derive or evaluate *if p then* . . . , first suppose *p*; for any proposition *q* that follows from the supposition of *p* taken together with other information assumed, one may assert *if p then q*.
   (schema for Conditional Proof.)

The conditional proof schema guides the understanding and use of conditionals. It says that "an *if* sentence is true when the antecedent, taken with other things the speaker knows, leads to the consequent" (Braine & O'Brien, 1991, p. 192).

An alternative view of the way people understand and reason from *and*, *or*, and *if* is that they construct models of the situation described by asser-

tions containing these connectives. They leave as much information as possible implicit in their models rather than spelling it out explicitly (for details see Johnson-Laird & Byrne, 1991, Chapter 3; Johnson-Laird, Byrne, & Schaeken, in press). Given a conjunction describing what is on a blackboard, such as:

*There is a circle and there is a triangle.*

reasoners construct models of the individual shapes and conjoin them to form the following sort of model:

○ △

With a disjunctive premise, such as:

*There is a cross or there is a star.*

they build two alternative models to represent the possibilities. We represent these two models by the following diagram:

\+

★

in which we adopt the notational convention of putting separate models on separate lines. A conditional, such as:

*If there is a circle then there is a triangle.*

calls for a model in which there is a circle and a triangle, but the assertion is consistent with a situation in which there is no circle. According to the theory, reasoners do not usually make explicit the nature of this alternative but represent its possibility in a second model, which has no explicit content:

[○] △

. . .

where the three dots denote such a model. It allows for a subsequent explicit content, and it rules out a conjunctive description of the models. The square brackets around the circle indicate that it is exhausted in relation to the triangle—it cannot appear without the triangle in any other model. The models can be fleshed out explicitly either as a conditional or as a bi-conditional. The conditional interpretation allows that a triangle may occur in the absence of a circle:

○ △

¬○ △

¬○ ¬△

where "¬" is a conceptual tag indicating negation (see Johnson-Laird & Byrne, 1989, for evidence of the use of such tags, and Johnson-Laird &

Byrne, 1991, Chapter 3, for a summary of the models for the different connectives).

Reasoners can make inferences from their models by adding the information from a subsequent premise, eliminating models that are inconsistent with it, and fleshing out models as the need arises (see also Byrne & Johnson-Laird, 1989; Johnson-Laird, Byrne, & Tabossi, 1989). For example, the categorical premise for modus ponens:

*There is a circle.*

is accommodated within the set of models by eliminating all but the first model:

[○] △

The model supports the conclusion:

*There is a triangle.*

which is valid because no other model of the premises falsifies it.

Our aim in this paper is to address the neglected question of how people *use* connectives. We will take a novel approach to the investigation of propositional connectives and try to answer the following question: in what circumstances do people use a particular connective to describe a situation?

Previous studies have had considerable difficulty in eliciting conditional descriptions (see Johnson-Laird, 1983, p. 46). When subjects are asked to describe a set of contingencies, they tend to use "disjunctive normal form", e.g. "*there is a circle and there is a triangle, or there is no circle and a triangle, or there is no circle and no triangle*", even though a conditional describes the same situation, i.e. "*if there is a circle then there is a triangle*". Later, we will propose an explanation for the elusiveness of conditionals, and we will demonstrate an effective method for their elicitation. But we will begin with the use of conjunctions and disjunctions in a constrained case—the task of paraphrasing conditionals—and then we will gradually move towards more realistic tasks.

## THE SPONTANEOUS USE OF "*AND*" AND "*OR*"

Suppose you are given a pair of conditionals of the following form:

If *p* then *q*
If *r* then *q*

and you are asked to combine them. What combination would you produce? Your choice of connective will depend on the content of the antecedents and, in particular, whether they are *alternatives* or *additional* antecedents. Your understanding is influenced by your general knowledge, as research on Wason's selection task has shown (for reviews see Evans, 1982;

Wason & Johnson-Laird, 1972). The distinction between alternative and additional antecedents is critical to the following experiments, and it was first introduced in a study of the suppression of inferences (Byrne, 1989). Consider the pair of conditionals:

*If she meets her friend then she goes to a play.*
*If she meets her brother then she goes to a play.*

General knowledge suggests that the antecedents describe *alternative* conditions that are independently sufficient for the outcome. Now consider the pair of conditionals:

*If she meets her friend then she goes to a play.*
*If she has enough money then she goes to a play.*

In this case, general knowledge suggests that the antecedents describe *additional* conditions that are jointly necessary for the outcome.

The model theory predicts that the *alternative* antecedents will be combined in a simple disjunctive antecedent:

*If she meets her friend* or *she meets her brother then she goes to a play.*

rather than conjunctively:

*If she meets her friend* and *she meets her brother then she goes to a play.*

Reasoners will represent the conditionals in a set of models of the following sort:

$$\begin{array}{ll} [f] & p \\ [b] & p \\ \ldots & \end{array}$$

where $f$ stands for meeting her friend, $b$ stands for meeting her brother, and $p$ stands for going to a play. The antecedents are represented as disjunctive alternatives (exhausted with respect to the outcome, though not to one another), and so an algorithm that describes models parsimoniously will generate a disjunction (see Johnson-Laird & Byrne, 1991, Chapter 9, for a description of a computational implementation of such an algorithm). The situation is a hypothetical one, as indicated by the three dots denoting the alternative possibilities, and it can be captured parsimoniously in a conditional.

The model theory predicts the *additional* antecedents will be combined conjunctively:

*If she meets her friend* and *she has enough money then she goes to a play.*

rather than disjunctively:

*If she meets her friend* or *she has enough money then she goes to a play.*

Reasoners will represent the conditionals by a set of models of the following sort:

[*f* *m*] *p*
. . .

where *m* stands for having enough money. The antecedents are represented as a conjunction (exhausted with respect to the outcome), and so they will be described conjunctively. Once again, the situation is hypothetical, and so a conditional connective will be used.

The rule theory makes similar predictions about the use of disjunctive and conjunctive combinations depending on the content of the assertions. Politzer and Braine (1991) suggest that the combination of a pair of conditionals, such as:

*If she has an essay to write then she will study late in the library.*
*If the library is open then she will study late in the library.*

would result in the assertion:

"*If she has an essay to write* and if *the library is open then she will study late in the library*"

(Politzer & Braine, 1991, p. 106, cf. Byrne, 1991). No rule is specified for the combination of syntactic forms, such as:

If *p* then *q*
If *r* then *q*

but we can infer that it would preserve the original two connectives and introduce a conjunction, to result in a *hypothetical* conjunction:

If *p* and if *r then q*

In summary, both theories predict that the choice of a disjunctive or conjunctive combination is guided by the interpretation of the antecedents as alternatives or additional conditions. The theories make different predictions about the connectives used to express these combinations. The model theory predicts *simple* disjunctions or conjunctions, such as *or* or *and*—an algorithm for combining conditionals describes parsimoniously what is true in the resulting model. The rule theory predicts *hypothetical* disjunctions or conjunctions, such as *or if* or *and if*—an algorithm for combining conditionals would not need to eliminate a conditional connective before introducing the new connective. The first two experiments test these predictions by examining the spontaneous use of conjunctions and disjunctions in a novel paraphrase task.

## EXPERIMENT 1

The first experiment was designed to test our predictions about the use of "and" and "or" in the paraphrase of conditionals. We gave subjects pairs of conditionals that contained either alternative or additional antecedents. Their task was to paraphase the two sentences, capturing their meaning in a single sentence.

### Method

*Materials and Design.* We constructed eight sets of conditionals about everyday events based on the materials in Byrne (1989). Each set of conditionals contained one basic conditional, e.g.:

*If she goes fishing then she has a fish supper.*

one conditional containing an alternative antecedent and the same outcome, e.g.:

*If she goes to the fishmarket then she has a fish supper.*

and one conditional containing an additional antecedent and the same outcome, e.g.:

*If she catches some fish then she has a fish supper.*

We consider an antecedent to be an alternative to the antecedent in the basic conditional if each antecedent is sufficient (in the absence of the other) to bring about the outcome. We consider an antecedent to be additional to the basic one if both are necessary to bring about the outcome.

The subjects were given two conditionals from each set: four pairs in which the antecedents were alternatives, and four pairs in which they were additionals (chosen at random from the eight sets, with the constraint that no subject received both the alternative antecedents and the additional antecedents from the same set, and each set was used equally often in the experiment as a whole). They were also given four further pairs of conditionals with contents based on arbitrary letters (e.g. "*If there is an A then there is a B*"). The 12 pairs of conditionals were presented in a different random order to each subject.

*Procedure.* Each sentence was printed on a separate sheet of paper. The subjects, who were tested individually, were asked to combine the two sentences to make a single sentence that preserved the meaning of the original sentences. They read the sentences aloud and then spoke their response, and the main connectives they used were recorded by the experimenter.

*Subjects.* Twenty-one women from the subject panel at the MRC Applied Psychology Unit, Cambridge, participated in the experiment. Their ages ranged from 27 to 59 years of age. Seven were replaced during ther course of the experiment, one because she had studied logic and the others because they were given trials that inadvertently omitted an item. They were paid £3 per hour for participating in the experiment, which lasted approximately 15 minutes.

## Results and Discussion

As we expected, the subjects used different connectives to combine the different sorts of conditionals. As Table 1 shows, subjects used more disjunctive combinations for the alternative antecedents (68%) than for the additional antecedents (10%), and every subject, apart from two ties, conformed to this pattern (binomial test, $p = 0.5^{19}$). Likewise, they used more conjunctive combinations for the additional antecedents (86%) than for the alternatives (30%), and every subject, apart from one tie, conformed to this pattern (binomial test, $p = 0.5^{20}$). The abstract pairs of conditionals yielded disjunctive combinations (50%) just as often as conjunctive combinations (49%; Wilcoxon's $T = 80.5$, $n = 17$, $p > 0.05$).

The connectives used to express the disjunctive and conjunctive combinations support the model theory and run counter to the rule theory. As the model theory predicts, subjects used *simple* conjunctions and disjunctions (90%) rather than *hypothetical* conjunctions or disjunctions (5%), and every single subject conformed to this pattern (binomial test, $p = 0.5^{21}$).

Subjects combine pairs of conditionals by using different connectives to distinguish between alternative and additional events. They describe alternative antecedents disjunctively, and they describe additional antecedents conjunctively. We have proposed that the phenomenon occurs because subjects construct different models for the two sorts of antecedents based on their general knowledge. The descriptions of models are parsimonious, capturing their hypothetical nature in a single conditional and their conjunctive or disjunctive nature equally simply. If knowledge does guide the construction of models, then an even freer paraphrase procedure should

TABLE 1
The Percentage of Disjunctive and Conjunctive Combinations of the Three Sorts of Conditionals in Experiment 1

| | *Alternatives* | *Additionals* | *Abstract* |
|---|---|---|---|
| Disjunctive combinations | 68 | 10 | 50 |
| Conjunctive combinations | 30 | 86 | 49 |

yield the same phenomenon. Our next experiment used a task in which the subjects were given simple assertions to paraphrase rather than conditionals.

## EXPERIMENT 2

Suppose you are given three independent assertions, such as:

*Mary goes fishing.*
*Mary catches some fish.*
*Mary has a fish supper.*

and you are asked to fit them together into a single conditional description, what combination would you produce? Three assertions can be combined into a single conditional, either by making two of them the antecedent and the third the consequent:

*If p and q then r*

or else by making one of them the antecedent and two of them the consequent:

*If p then q and r*

There are six possible orders in which the assertions can be used in either of the formulae, and obviously the combined antecedents or consequents can be conjunctive or disjunctive. But most of these 24 possibilities should never occur, because you can use your general knowledge to guide your description. You should be able to determine which of the three events is the potential outcome, i.e.:

*Mary has a fish supper.*

and to establish that the other events are antecedents that bring about this outcome. You should also be able to determine whether these antecedents are alternative or additional events, and thus to construct integrated descriptions, such as:

*If Mary goes fishing and catches some fish then she has a fish supper.*

The model theory predicts that you construct a model of the situation, and you describe this model parsimoniously using simple conjunctions or disjunctions as appropriate. However, there is more than one way to describe a model, such as:

$$[f \quad c] \quad s$$
$$\ldots$$

where $f$ stands for Mary goes fishing, $c$ stands for her catching some fish, and $s$ stands for her having a fish supper. For example, an alternative way

to describe the same construal of the events is to use the antecedent of the conditional to state the outcome, which then provides evidence that certain conditions have been satisfied:

*If Mary had a fish supper then she went fishing and caught some fish.*

Philosophers sometimes refer to such conditionals as "epistemic". Either format captures the same essential relations, although the latter calls for the use of the past tense and thus for changes in the literal wording of the original sentences. This factor may therefore reduce the frequency with which this sort of paraphrase occurs. Nonetheless, in this freer paraphrase task, we expect a rich variety of descriptions of the events.

According to the rule theory (Braine & O'Brien, 1991) the way to generate a conditional is, first, to assume its antecedent, then to determine what follows from this assumption (and any other general knowledge), and finally—granted that a conclusion corresponding to one or other proposition is forthcoming—the conditional as a whole can be asserted: *if p then q*. The reasoner's task is therefore to determine which proposition, or pair of propositions, validly implies the remaining proposition(s). The problem with this account of our task is that none of the propositions follows from the other members of the pair. Suppose you want to deduce the conclusion:

*Mary has a fish supper.*

from the premises:

*Mary goes fishing.*
*Mary goes to the fishmarket.*

What you need is a premise, such as:

*If Mary goes fishing or she goes to the fishmarket then she has a fish supper.*

Now you can deduce the conclusion from the premises. But where is this conditional premise to come from? According to Braine and O'Brien, you can only generate it if its conclusion follows from its premises. But it was precisely this demand that led to the need for the conditional in the first place. The theory leads to a small and vicious circle. In short, it is quite unable to explain how anyone could generate a conditional in which the conclusion does not follow from the premises. The model theory does not labour under this difficulty. It allows that a conditional can be generated merely because it is a *true* description (of a set of models). In summary, the experimental task ought to be impossible according to the rule theory, whereas it is entirely feasible according to the model theory. In addition, the model theory allows for a variety of syntactic forms of paraphrase, whereas even if the rule theory could explain the generation of contingent

conditionals, it would seem to be committed to the view that they invariably take the form: *if p then q*. We tested the predictions of the two theories by asking subjects to combine sets of three simple assertions into a single conditional assertion.

## Method

*Materials and Design.* We constructed eight sets of materials, and each contained four simple assertions. These materials were derived from those in the previous experiment, except that we replaced the pronouns with proper names. Each set contained a potential outcome (the consequent of the basic conditional in the previous experiment), e.g.:

*Mary has a fish supper.*

a basic antecedent (from the basic conditional in the previous experiment), e.g.:

*Mary goes fishing.*

an alternative antecedent (from the alternative conditional in the previous experiment), e.g.:

*Mary goes to the fishmarket.*

and an additional antecedent (from the additional conditional in the previous experiment), e.g.:

*Mary catches some fish.*

The subjects were given three assertions from each set: every set contained an outcome assertion, a basic antecedent, and either an alternative or an additional antecedent. They received four triplets in which the antecedents were alternatives, and four triplets in which they were additionals (chosen at random from the sets, with the constraint that no subject received both the alternative and the additional antecedents from the same set, and that each set was used equally often in the experiment as a whole). Each triplet of sentences was presented in a random order to the subject, and the order of the sets was also randomized for each subject.

*Procedure.* The sentences were printed on separate sheets of paper. The subjects, who were tested individually, were asked to combine the three sentences to make one sensible sentence. They could combine the sentences in any order, and there was no need to repeat the proper names, but they were required to use *if* in the sentence. They were allowed to use other words as well. (A sheet of paper with *if* printed on it remained before them throughout the experiment.) They read the sentences aloud and then wrote their response to each triplet on a separate sheet of paper.

*Subjects.* Nineteen women from the subject panel at the MRC Applied Psychology Unit, Cambridge, participated in the experiment. Their ages ranged from 24 to 71 years. Two were replaced during the course of the experiment because they had failed to complete all of the items in their set. The subjects were paid £3 per hour for participating in the experiment, which lasted for approximately 15 minutes.

## Results and Discussion

Subjects produced a rich variety of descriptions to express their paraphrases. The most frequent expressions, used on at least four or more occasions, were:

*if p or q, r*
*if p and q, r*
*if p or if q, r*
*p and if q, r*
*if p, q and r*
*if p, q, r*
*p if r when (because) q*

Most paraphrases of the triplets containing additional antecedents (61%) combined the additionals in the antecedent and the outcome in the consequent. In this case, nearly all the combinations (98%) used a conjunction, e.g.:

*If Mary goes fishing and catches some fish then she has a fish supper.*

rather than a disjunction (2%), and every subject, apart from one tie, conformed to this pattern (binomial test, $p = 0.5^{18}$). Likewise, many paraphrases of the triplets that contained alternatives (53%) combined the alternatives in the antecedent and the outcome in the consequent. In this case, most of the combinations (58%) used a disjunction, e.g.:

*If Mary goes fishing or goes to the fishmarket then she has a fish supper.*

although many used a conjunction (43%), such as:

*If Mary goes fishing and goes to the fishmarket then she has a fish supper.*

and there was no reliable difference between them (Wilcoxon's $T = 86.5$, $n = 18$, $p > 0.05$).

Once again, the descriptions used to convey these conjunctions and disjunctions support the model theory and run counter to the rule theory. Subjects constructed more simple conjunctions and disjunctions (71%) than hypothetical conjunctions or disjunctions (29%, using a generous scoring system in which even combinations, such as *r when p if q* are adjudged to

favour the rule theory), and this difference is relaible (Wilcoxon's $T = 23.5$, $n = 17$, $p < 0.01$).

Subjects generated epistemic or evidential conditionals on 15% of trials overall, i.e. conditionals in which the antecedent provides evidence for the consequent. This category of description, and indeed the rich variety of descriptions overall, is easy to explain if descriptions are generated by an algorithm that describes models. It is less easy to explain if descriptions are generated by a single syntactic schema for conditional proof, even if that schema could somehow be used where the consequent does not follow validly from the antecedent.

In Experiment 1, the subjects were asked to form a single paraphase of two given conditionals. In the present experiment, they were asked to form a single conditional to paraphase three simple assertions. In both cases, their choice of connectives was evidently guided by their knowledge of the events they were describing, and this knowledge led them to construct different models of sentences of the same linguistic form. Our final experiment attempted to test more directly the effect of different models on paraphrases. It used an entirely free paraphrase task, in which we asked subjects to paraphrase three simple sentences but gave them no instructions about the form that their paraphrases should take.

## THE SPONTANEOUS USE OF *"IF"*

### EXPERIMENT 3

It is difficult to elicit a conditional description by asking people to describe a set of contingencies (see Johnson-Laird, 1983, p. 46). In the first two experiments, we gained some control over subjects' choices of disjunctive and conjunctive connectives using a paraphrase task, and so we decided to apply the same method to conditionals. We presented subjects with three simple assertions, in a random order, such as:

*Paul cooks a meal*
*Paul uses decent ingredients.*
*Paul has a pleasant meal.*

and we asked them to make a sensible paraphrase using any words they wished. We did not instruct them to use a conditional, or to use any other connective. The only constraint was that their paraphrase should be a single sentence.

This task confronts subjects with two inter-related problems. One is to find a framework that makes sense of the three assertions, and the other is to relate the three assertions together within that framework. Subjects are likely to represent the three assertions in a single temporal model. This

model contains three main referents (*Paul, the ingredients, the meal*), the relations among them (*Paul cooks the meal using the ingredients, Paul eats the meal*), the properties of the referents (*the ingredients are decent, the meal is pleasant*), and the temporal relation between the two main events (*the cooking precedes the meal*). Models are therefore quite complex structures representing entities, relations, and properties, but these details need not concern us here. The important point is that the subjects construct just a single model, which we will represent by the following simple diagram:

*c d p*

where *c* stands for Paul cooking a meal, *d* stands for him using decent ingredients and *p* stands for him having a pleasant meal. A single model should elicit a simple temporal or causal assertion, e.g.:

*When Paul cooks a meal and uses decent ingredients, he has a pleasant meal.*

Now consider the same three assertions, but this time with a modal verb in the assertion describing the outcome:

*Paul cooks a meal.*
*Paul uses decent ingredients.*
*Paul can have a pleasant meal.*

The presence of the modal verb "can", conveys the fact that the outcome event may, or may not, occur. The assertion is analogous to the following:

*It is possible that Paul has a pleasant meal.*

and the meaning of "possible" ensures the construction of a model in which the event occurs (Johnson-Laird, 1978), but there is an alternative possibility to the one described in the sentence, i.e. an alternative to Paul having a pleasant meal. Hence, the assertion calls for one explicit model and an alternative, implicit, model:

[*c d*] *p*
. . .

This combination of an explicit model containing an outcome and an implicit model that might not contain it corresponds to the set of models postulated for a conditional assertion, according to our theory. We therefore predicted that subjects would be more likely to use a conditional to paraphrase the three assertions when the outcome sentence contained a modal verb than when it did not.

The rule theory makes different predictions. Because, as we have seen, the outcome cannot be deduced from the other assertions, conditionals should not be used to describe either the set of assertions containing a modal or the set of assertions not containing a modal. Even if, somehow, conditionals could be generated, the theory cannot predict any difference

between the two sorts of materials. The conditional proof schema applies either equally or not at all to the sets of assertions. Our final experiment was designed to test the predictions of the two conflicting theories.

We also examined how subjects paraphrased assertions containing negatives. We included "all-negative" sets of assertions, such as:

*There are no boats available.*
*The boats are not in working condition.*
*Alicia cannot go rowing.*

where we predicted that the main connective would be *if* or a similar construction. We also included "negative outcome" sets, containing affirmative antecedents but a negative outcome, such as:

*There are boats available.*
*The boats are in working condition.*
*Alicia cannot go rowing.*

The corresponding set of three affirmative assertions, such as:

*There are boats available.*
*The boats are in working condition.*
*Alicia can go rowing.*

can be represented in the models:

$[a \quad w] \quad r$
$\ldots$

where $a$ stands for there being boats available, $w$ stands for them being in working order, and $r$ stands for Alicia being able to go rowing. This model can be described in the conditional:

*If there are boats available and the boats are in working condition, Alicia can go rowing*

But when the outcome is negative it conflicts with this usual sequence of events, and must be represented in a separate model from the antecedents:

$a \quad w$
$\neg r$
$\ldots$

The theory predicts that these models will be described using a hypothetical construction, because there are two alternatives to the antecedent model. But *if* cannot be used to connect the antecedent to the negative outcome, because the two are in different models. A connective that does express the appropriate relation (Fillenbaum, 1986; Smith, 1983) is *unless*, e.g.:

*Unless there are boats available and the boats are in working condition, Alicia cannot go rowing.*

Thus, the theory predicts that subjects will combine the negative outcome assertions using a connective such as, "unless". It is unclear what predictions, if any, the rule theory makes about these materials. A conditional proof schema might be formulated for *unless*, e.g.:

> To derive *q unless p* first suppose *not-p*; for any proposition *q* that follows from the supposition of *not-p*, taken together with other information assumed, one may assert *q unless p*.

Once again, however, there is an impasse: the antecedent assertion, *q*, does not follow validly from the negative outcome, and so it is difficult to see how the rule theory could yield a paraphrase.

## Method

*Materials and Design.* The materials were again derived from the materials used in the previous experiments. We constructed one version in which every outcome sentence contained a modal verb, e.g.:

*Joe hires a gardener.*
*Joe does some gardening.*
*Joe can get the grass cut.*

and a second version, in which the outcome sentences did not contain a modal verb, e.g.:

*Joe hires a gardener.*
*Joe does some gardening.*
*Joe gets the grass cut.*

Each version contained four sets that contained affirmative assertions, such as the ones above, four sets that contained "all-negative" assertions, e.g.:

*Joe does not hire a gardener.*
*Joe does not do some gardening.*
*Joe cannot get the grass cut.*

and four sets that contained "negative-outcome" assertions:

*Joe hires a gardener.*
*Joe does some gardening.*
*Joe cannot get the grass cut.*

We constructed 12 concrete domains for the propositions and assigned the lexical materials to the sets in two ways: half the subjects were given one set and the other half the other set.

Each subject carried out 12 trials, in a different random order, based on the four affirmative sets of materials, four "all negatives" and four

"negative outcomes". Two of the trials with each set used additional antecedents and two used alternatives (chosen at random). Within each trial, the triplets were presented in a different random order to each subject. One group of 18 subjects received the "modal" materials and a second group of 9 subjects received the "non-modal" materials.

*Procedure.* The procedure was the same as in the previous experiment, except that the subjects were asked to combine the three sentences using any words they wanted (i.e. they were *not* instructed to use *if*).

*Subjects.* Twenty-seven subjects (21 women and 6 men) from the subject panel at the MRC Applied Psychology Unit, Cambridge, participated in the experiment. Their ages ranged from 22 to 64 years. They were paid £3 per hour for participating in the experiment, which lasted just under a half an hour.

## Results and Discussion

The results support our predictions. As Table 2 shows, the subjects in the modal group (36%) used *if* and *unless* more often than the subjects in the non-modal group (5%) and this difference was reliable [Mann-Whitney $U(9, 18) = 10.5$, $p < 0.001$]. The difference was reliable for the affirmative materials [26% v. 6%, Mann-Whitney $U(9, 18) = 46$, $p < 0.05$] for the all-negative materials, 39% vs. 3%, Mann-Whitney $U(9, 18) = 27.5$, $p < 0.01$, and for the negative outcome materials [44% vs. 6%, Mann-Whitney $U(9, 18) = 25.5$, $p < 0.01$].

The subjects used a variety of connectives in their descriptions, and Table 3 presents the percentages of the most frequent sorts. As it shows, the subjects used *if* spontaneously when the outcome assertion described a possibility. They used factual connectives, such as *so* and *as*, when the outcome assertion was asserted categorically. These results go against the theory that subjects rely on a schema for conditional proof: if they did,

TABLE 2
The Percentages of Descriptions Containing *If* and *Unless* for Affirmative Assertions, All-negatives, and Negative Outcomes Produced by the Subjects in the Modal and Non-modal Groups in Experiment 3

| | *Affirmative* | *All-negatives* | *Negative Outcome* |
|---|---|---|---|
| Modal | 26 | 39 | 44 |
| Non-modal | 6 | 3 | 6 |

TABLE 3
The Percentages of Various Sorts of Descriptions for Affirmative Assertions, All-negatives, and Negative Outcomes Produced by the Subjects in the Modal and Non-modal Groups in Experiment 3

| | *Affirmative* | | *All-Negatives* | | *Negative Outcome* | |
|---|---|---|---|---|---|---|
| *Connective* | *Modal* | *Non-modal* | *Modal* | *Non-modal* | *Modal* | *Non-modal* |
| if | 26 | 6 | 36 | 0 | 6 | 6 |
| unless | 0 | 0 | 3 | 3 | 38 | 0 |
| and | 14 | 22 | 4 | 3 | 0 | 3 |
| but | 0 | 3 | 0 | 0 | 14 | 47 |
| so | 4 | 28 | 6 | 42 | 6 | 17 |
| as | 8 | 17 | 10 | 33 | 4 | 0 |
| although | 0 | 6 | 3 | 0 | 10 | 11 |
| when | 8 | 6 | 4 | 6 | 3 | 3 |
| to | 10 | 0 | 0 | 0 | 0 | 0 |
| therefore | 1 | 0 | 8 | 6 | 0 | 3 |
| in spite of | 0 | 0 | 0 | 0 | 0 | 8 |

*Note:* Connectives used in combination, e.g. *although . . . so as to*, are classified under the main connective. Only connectives used on 5% or more of trials in at least one condition are included—other connectives such as *because, while, where, whether, by, thus, without, after*, were used on less than 5% of trials, and relative clauses (indicated by *who*) were used on 7% of trials overall.

there would be no difference in their use of *if* and *unless* in the modal and non-modal conditions. The modal verb in the outcome assertion makes subjects aware that the events might not occur. Their representation of the events captures the possibility of alternative situations, e.g.:

$$[p \quad q] \quad r$$
$$\ldots$$

According to the model theory, this set of models corresponds to the initial representation of a conditional, and so the subjects spontaneously used conditionals.

## GENERAL DISCUSSION

In what circumstances do people spontaneously use the connectives *if*, *and*, and *or*? In our first experiment, the subjects were set the task of forming a single conditional that paraphrased two others with a consequent in common, and their responses were reliably affected by the content of the antecedents of the initial pair of sentences. If the two antecedents described two conditions that were jointly necessary to bring about the consequent

event, then the subjects combined the antecedents conjunctively, and they expressed the conjunction using a simple conjunction *and*, rather than a hypothetical conjunction *and if*. Likewise, if the two antecedents described two alternatives that were each sufficient to bring about the consequent event, then the subjects combined the antecedents disjunctively, and they expressed the disjunction using a simple disjunction *or*, rather than a hypothetical disjunction *or if*.

The same phenomena occurred in Experiment 2, in which the task was to combine three separate assertions into a single conditional description. The subjects were generally able to identify which of three assertions described the outcome and to construct a conditional that integrated the three events in a coherent way, choosing a simple conjunction or disjunction appropriately. The results bear out our proposal that general knowledge guides the construction of models, and that people can generate a rich variety of descriptions of what is true in their models. One such description, the orthodox conditional, relates antecedent events to an outcome. In another such description, the evidential conditional, the antecedent does not lead to the consequent but rather, provides evidence that the consequent occurred. In contrast, the rule theory posits that conditionals are generated according to the schema for conditional proof, and so the consequent must follow validly from the antecedent (and other information that can be taken for granted). Unfortunately, as we showed, this prerequisite leads to a small vicious circle: in order to generate a conditional of the form *if p then q* from the constituents *p* and *q*, one needs such a conditional to establish that *q* follows from *p*.

Perhaps the most striking finding, however, occurred in Experiment 3. Here, the subjects were asked to construct a single-sentence paraphrase of three independent assertions, and they were not told that it should be a conditional. They were free to choose any connectives whatsoever. Our theory predicted that three definite assertions that can be interpreted in a causal framework would tend to be paraphrased factually, e.g. using *so*, *when*, or other such connectives. But where an outcome is described in a sentence containing the modal auxiliary *can*, e.g. "*Alicia can go rowing*", then the outcome is clearly only a possibility. Hence, subjects are likely to envisage two alternatives—one in which the outcome occurs and one in which it does not occur. According to the theory, this set of models corresponds to those for a conditional. Hence, we predicted that subjects would use a conditional in their paraphrase. The rule theory predicts no such difference, since the conditional proof schema would apply equally well, if at all, to the materials in either condition. The results of the experiment corroborated the model theory. They also showed, as we predicted, that subjects would tend to use a hypothetical construction such as *unless* to connect the antecedent events to a negative outcome, e.g.:

*Unless there are boats available and the boats are in working order, Alicia cannot go rowing.*

As a conditional schema for *unless* also requires one proposition to follow from another, it is as impotent as the conditional proof schema in generating hypothetical constructions.

There has been increasing interest in the effects of modal verbs on the inferences people make (Cheng & Holyoak, 1985; Manktelow & Over, 1990, 1991; Piéraut-Le Bonniec, 1980). Their effects do seem to be explicable in terms of the theory of reasoning based on mental models that we have outlined (e.g. Johnson-Laird & Byrne, 1991). The modal verb cues the construction of a set of alternative models that are intrinsically hypothetical, whereas in its absence a single factual model is constructed. The theory also explains why it has been difficult in the past to elicit conditionals (e.g. Johnson-Laird, 1983). When presented with a set of contingencies, such as a truth table, subjects describe the events using disjunctive normal form, rather than using a more concise conditional construction. According to the theory, subjects initially represent conditional information by constructing an explicit model of the events, and an implicit model that corresponds to alternatives to the events. Their initial representation does not contain information corresponding explicitly to each possibility, as a truth table does, nor does it contain information corresponding to what is not the case, as a truth table does. It is likely that they are overwhelmed by the information in a truth table, and it is not surprising that they do not describe it conditionally.

Could a formal rule theory be formulated that would account for the results of these experiments? It would need at least two principal modifications: (1) The theory would need to escape from the vicious circle created by the demand that one proposition follows from another, if the conditional proof schema is to be used to generate a conditional. In our view, the only way out is to substitute a claim about *truth* rather than *validity*, i.e. a conditional *if p then q* is true, given a set of alternative models of the world containing one model in which $p$ is exhausted in relation to $q$. Of course such an assumption introduces a full-fledged semantics into the theory, but the step is necessary in any case because the whole burden of twentieth century logic is that semantics cannot be reduced to formal rules (*pace* Braine & O'Brien, 1991): the proof of the *incompleteness* of second-order logic shows that no sound set of formal rules can capture all the true assertions in that logic (see, e.g. Boolos & Jeffrey, 1980, p. 204). (2) The theory would need an analysis of a variety of connectives, such as *so*, *as*, and *when*. A theory with these two components, however, would be difficult to distinguish from the model theory.

Our research represents a first step towards understanding how general knowledge affects the construction of models, which, in turn, govern the

construction of sentences. The attempt to gain experimental control over the use of connectives has proved to be an unusual enterprise. On the one hand, it was relatively easy to set up tasks in which conjunctions and disjunctions are used quite naturally. On the other hand, it was much more difficult to create experimental contexts in which subjects spontaneously used conditionals. The experimental control over the production of conditional descriptions is, to our knowledge, the first successful manipulation of its kind. The free paraphase of independent propositions is a potentially useful paradigm for investigating the spontaneous production of connectives in general.



## REFERENCES


Boolos, G.S., & Jeffrey, R.C. (1980). *Computability and logic* (2nd Edition). Cambridge: Cambridge University Press.

Braine, M.D.S. (1978). On the relation between the natural logic of reasoning and standard logic. *Psychological Review*, *85*, 1–21.

Braine, M.D.S., & O'Brien, D.P. (1991). A theory of *if*: A lexical entry, reasoning program, and pragmatic principles. *Psychological Review*, *98*, 182–203.

Byrne, R.M.J. (1989). Suppressing valid inferences with conditionals. *Cognition*, *31*, 61–83.

Byrne, R.M.J. (1991). Can valid inferences be suppressed? *Cognition*, *39*, 71–78.

Byrne, R.M.J., & Johnson-Laird, P.N. (1989). Spatial reasoning. *Journal of Memory and Language*, *28*, 564–575.

Byrne, R.M.J., & Johnson-Laird, P.N. (1990). Models and deduction. In K. Gilhooly, M.T.G. Keane, R. Logie, & G. Erdos (Eds.), *Lines of thought: Reflections on the psychology of thinking*. London: Wiley.

Cheng, P.N., & Holyoak, K.J. (1985). Pragmatic reasoning schemas. *Cognitive Psychology*, *17*, 391–416.

Evans, J.St.B.T. (1982). *The psychology of deductive reasoning*. London: Routledge & Kegan Paul.

Fillenbaum, S. (1986). The use of conditionals in inducements and deterrents. In E.C. Traugott, A. Ter Meulen, J.S. Reilly, & C.A. Ferguson (Eds.), *On conditionals*. Cambridge: Cambridge University Press.

Johnson-Laird, P.N. (1978). The meaning of modality. *Cognitive Science*, *2*, 17–26.

Johnson-Laird, P.N. (1983). *Mental models: Towards a cognitive science of language, inference, and consciousness*. Cambridge: Cambridge University Press; Cambridge, MA: Harvard University Press.

Johnson-Laird, P.N., & Byrne, R.M.J. (1989). *Only* reasoning. *Journal of Memory and Language*, *28*, 313–330.

Johnson-Laird, P.N., & Byrne, R.M.J. (1991). *Deduction*. Hove: Lawrence Erlbaum Associates.

Johnson-Laird, P.N., Byrne, R.M.J., & Tabossi, P. (1989). Reasoning by model: The case of multiple quantification. *Psychological Review*, *96*, 658–673.

Johnson-Laird, P.N., Byrne, R.M.J., & Schaeken, W. (in press). Reasoning by model: The case of propositional inference. *Psychological Review*.

Manktelow, K.I., & Over, D.E. (1990). Deontic biases in human thought. In K. Gilhooly, M.T.G. Keane, R. Logie, & G. Erdos (Eds.), *Lines of thought: Reflections on the psychology of thinking*. London: Wiley.

Manktelow, K.I., & Over, D.E. (1991). Social roles and utilities in reasoning with deontic conditionals. *Cognition*, *39*, 85–105.

Piéraut-Le Bonniec, G. (1980). *The development of modal reasoning: Genesis of necessity and possibility notions*. New York: Academic Press.

Politzer, G., & Braine, M.D.S. (1991). Responses to inconsistent premises cannot count as suppression of valid inferences. *Cognition*, *38*, 103–108.

Rips, L.J. (1983). Cognitive processes in propositional reasoning. *Psychological Review*, *90*, 38–71.

Smith, N.V. (1983). On interpreting conditionals. *Australian Journal of Linguistics*, *3*, 1–23.

Wason, P.C., & Johnson-Laird, P.N. (1972). *Psychology of reasoning: Structure and content*. London: Batsford; Cambridge, MA: Harvard University Press.

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