Priming in deduction: A spatial arrangement task

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The mental model theory assumes that people reason by manipulating mental representations of states of the world, called “mental models.” In the present study we used a new deduction task based on diagrammatic premises. We show that a premise can prime other premises that induce similar mental models in a way analogous to the case of words with related meanings, which can prime one another. We present three experiments. In Experiment 1 we used an evaluation task. In Experiment 2, a construction task was used. The priming effect was obtained in both cases. In a third experiment we show that the priming effect was still present when participants were instructed to ignore a prime displayed before the premises. In all three experiments we compared determinate and indeterminate problems and found faster responses in the former.

There are two main groups of psychological theories of deduction, each proposing a different algorithm in relation to how people make inferences. On the one hand, the mental rule theories (Braine & O'Brien, 1998; Braine, Reiser, & Romain, 1984; Inhelder & Piaget, 1958; Rips, 1994) assume that reasoners apply abstract rules that lead to a validation of logical arguments. The mental model theories (Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991; Polk & Newell, 1995), on the other hand, assume that people reason by creating and manipulating representations of possible states of affairs, called “mental models.” This study focuses on the mental model theory. Some examples of mental models will be given below.

Despite the fact that they were intended as domain-general theories of cognition (Thompson, 2000), both theories were created to explain the results of propositional tasks. However, these propositional tasks (see Evans, Newstead, & Byrne, 1993) may not be sensitive enough for studying some deductive processes. These tasks are usually deliberately made complex in order to detect differences in accuracy. Reaction time is not informative in these tasks because, normally, very few trials are used. However, many recent studies have used reaction time, simplifying to some extent the traditional tasks (e.g., García-Madruga, Moreno, Carriedo, Gutiérrez, & Johnson-Laird, 2001;

Lea, 1995; Schaeken, Johnson-Laird, & d'Ydewalle, 1996) and bringing them closer to those used in other fields of cognition.

Interestingly, studies measuring reaction times have supported the assumption that during comprehension people construct models of reality (Glenberg, Meyer, & Lindem, 1987; Langston, Kramer, & Glenberg, 1998). Text comprehension is faster when the new information is related to the previous information because it can be integrated or updated in the same mental model without requiring the construction of a new model (Garnham, Traxler, Oakhill, & Gernsbacher, 1996; Glenberg, 1997).

These studies have examined the course of activation of the mental representations during comprehension (see Gernsbacher, 1997). The procedure is based on the priming effect (Meyer & Schvaneveldt, 1971), which consists of a reduction in the time required to respond to a target stimulus (e.g., the word *tree*) when the same stimulus or a related stimulus (*branch*) has been previously processed. The effect is called “repetition priming” when the stimulus is the same target and “semantic priming” when the meaning of the stimulus is related to that of the target (see Neely, 1991, for a review). For example, let us assume that an ambiguous word such as *branch* is presented before a related target word, such as *tree* or *bank*. In this case, reading the target or giving a response to it is faster than when the previously presented word and the target are unrelated, such as *branch* and *disk*. Priming occurs even when participants are instructed not to consider the prime word (Gernsbacher & Faust, 1995).

In general, priming is explained by assuming the existence of a representation activated by the first stimulus, which facilitates processing of the subsequent stimulus ei-

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ther by allowing its integration in the same representation (see "meshing" in Glenberg, 1997; also Gernsbacher, 1997; Hess, Foss, & Carroll, 1995) or by spreading the activation to all the semantic associates of the first stimulus, and hence also to the related target (see Neely, 1991; see, however, Ratcliff & McKoon, 1988, for an alternative explanation).

Many versions of this skeletal priming task have been used to study mental representation, ranging from text comprehension (Glenberg, 1997) to social cognition (Fazio, Jackson, Dunton, & Williams, 1995). Most of them present texts describing a situation rather than just single words. The requested response may vary, from just reading the target to making a lexical decision or a probability judgment (Betsch & Fiedler, 1999).

In the present experiments, we used a new approach that introduces a priming measure to study the algorithm of deduction. At least one of the above-mentioned theories of reasoning, the mental model theory, can guide us in this study by offering some detailed predictions. According to this theory, it should be possible to prime particular mental models, thus affecting the process of deduction.

The mental model theory maintains that people make deductions in three linked stages: (1) In the *comprehension* stage, they represent the information contained in the premises. Look at the following example about the possible arrangements of three balls ("A," "B," and "C"):

B is on the right of A.
C is on the left of A.
What is the correct arrangement of the three balls?

According to the model theory, the representation of the first premise, "A B," is integrated with the information in the second premise, "C A," leading to the "C A B" representation (which means that "C" is on the left, "A" in the middle, and "B" on the right). There is only one possibility, and this kind of problem is therefore called a "determinate problem." The next example is an *indeterminate problem*:

B is on the right of A.
C is on the left of B.
What is the correct arrangement of the three balls?

In this problem reasoners could construct both "C A B" and "C B A." The model theory holds that representing

multiple mental models is more difficult than representing just one.

In the second stage (2), *description* of a tentative conclusion, people propose a conclusion; for example, "C is on the left of B" (C A B).

In the final stage (3), *validation*, the conclusion is reconsidered to confirm that it is the only one possible. Some tasks do not require this stage. For example, in "evaluation of the sufficiency tasks," reasoners have to decide whether a conclusion is possible rather than deciding whether it is necessary (i.e., the only possible conclusion).

One typical way of testing predictions of the mental model theory is to compare the degree of difficulty of determinate and indeterminate problems (Johnson-Laird, Byrne, & Schaeken, 1992). The theory predicts that with indeterminate problems, people have to construct multiple mental models, which takes longer and leads to an increase in the number of errors. Byrne and Johnson-Laird (1989) tested this prediction, finding that even when people were asked after each problem "Is C on the left of A?" correct "yes" decisions were less frequent with the indeterminate problem than with the determinate one. Response times were not measured in this study.

The aim of the present study was to test whether particular mental models can be primed and also to contrast determinate and indeterminate problems. Because we sought to measure reaction times, we used a new task that simplifies the cognitive components of traditional reasoning tasks. The comprehension stage is simplified by (1) using diagrammatic premises instead of propositional ones (Bauer & Johnson-Laird, 1993) and (2) avoiding the need to integrate information from the premises, which requires effort (Maybery, Bain, & Halford, 1986). Also, the validation stage was simplified by (3) asking people to evaluate possible conclusions instead of having to generate them. An example of the task is shown in Figure 1.

The first premise shown in Figure 1 means that Ball C cannot be on the right. The second premise tells us that Ball C is in the middle, and the third establishes that Ball B is on the left and Ball C is in the middle. Finally a conclusion is shown, which must be evaluated: Given the previous information, is the following arrangement possible? "B" on the left, "C" in the middle, and "A" on the right?

Figure 1. Example of a typical trial used in Experiments 1 and 2 and its time sequence. Three premises and the conclusion were shown on four separate screens.

Table 1
Examples of Two- and Three-Premise Conditions

Problem	Condition	
	Control	Experimental
Indeterminate		
Premise 1	-- €	-- €
Premise 2	---	- C -
Evaluation (correct response: "yes")	B C A	B C A
Problem	Condition	
	Control	Facilitated
Determinate		
Premise 1	-- €	-- €
Premise 2	---	- C -
Premise 3	B C -	B C -
Evaluation (correct response: "yes")	B C A	B C A

Note—€, Ball C is not in the mentioned position; -, no information is offered about which ball is in the mentioned position (A, B, or C).

EXPERIMENT 1 Evaluation of Sufficiency

If people manipulate models when they consider different possibilities in deduction, as the model theories maintain, then the representation of those possibilities (models) should show a sequence of states of activation. In order to study such a sequence, we used an artificial task in which the maximum number of possibilities is six—the permutations of three balls labeled "A," "B," and "C." Each model corresponds to a possible configuration of the three balls, and the premises give information that restricts the number of initial possibilities.

The experimental task can be seen as the analysis of the solution to the complex problem shown in Figure 1, broken down into four simpler problems that increase in complexity and constitute the four conditions in this experiment. Let us consider the predicted activation of models after reading each premise of the complex problem in turn. The first premise tells us that Ball C cannot be on the right. The second premise tells us that Ball C is in the middle. Given the first premise, two configurations (A B C and B A C) out of six are impossible (and four are possible). With the second premise, the opposite occurs: Two configurations (A C B and B C A) out of six are possible (and four are impossible).

The model theory assumes that, because working memory is limited, people construct the smallest possible set of models. We would expect the construction of two rather than four models and hence, responses to either of these two models would be faster than any of the four models.

This prediction, however, may appear inconsistent with the "principle of truth" and merits a comment. This principle, based on the above assumption, states that individuals tend to minimize the load on working memory by representing explicitly only what is true and not what is false (see Johnson-Laird & Savary, 1999). The mental model theory agrees with this principle in many inference tasks, especially with disjunctions. However, Johnson-Laird (2000, p. 176) noted that the theory predicts that some manipulations may make it easier for participants to

envisage what is false. Importantly, as Santamaría and Johnson-Laird (2000) demonstrated, the limitation in representing explicitly what is false (or impossible) does not hold when people think about "physical alternatives," as occurred in our study. In our task, people have to think about possible (true) and impossible (false) arrangements of balls. Because this task is about physical alternatives, the prediction is that they will represent the smallest set of models, whether possible or impossible.

Consequently, we predicted that the principle of truth would not hold in the present task. If a conclusion is evaluated after the first premise, the response will be faster when it is impossible than when it is possible, because the last informative premise is negative (Table 1), and the opposite should occur with the second premise, because it is affirmative. The control and experimental conditions provided us with both situations.

The third premise establishes that Ball B is on the left and Ball C is in the middle. Ball A must be on the right, thus leaving only one possibility. This is a determinate problem, which corresponds to the determinate condition in Table 1.

The mental model theory enables us to make a clearer prediction than the previous one: Determinate problems will be resolved more quickly than indeterminate problems, and therefore a conclusion will be evaluated more quickly after the third premise (which makes the problem determinate) than after the first or second premise.

The final prediction is related to facilitation by priming. In order to carry out the test, facilitated and control conditions in determinate problems (see lower part of Table 1) were compared. As we have seen, processing the word *tree* is facilitated when it is preceded by *branch*, a related word (facilitated condition), but not when it is preceded by *disk*, an unrelated word (control condition). Similarly, the third premise, "B C -," shown in both conditions, activates the mental model "B C A." In the facilitated condition, the previous second premise, "- C -," also activates the model "B C A," which would lead to a faster response to it (priming effect). In contrast, in the control condition, the second premise, "-- -," does not activate the same model, and therefore no priming effect is expected.

Method

Participants. Thirty-two male and female students from the UNED took part. They received experimental credits as compensation for their participation. All were students in Madrid, registered in the 3rd year of a developmental psychology course. All had normal or corrected vision. The participants did not know the objectives of the research.

Stimuli and Apparatus. The experiment was programmed using PsyScope (Cohen, MacWhinney, Platt, & Provost, 1993) and carried out on a Macintosh computer. Stimuli were displayed on the computer screen with characters in black (Chicago, 12 point) on a white background. The first premise was always a restrictive premise, represented by a letter with a red line crossing it from left to right and from top to bottom. Participants were seated in front of a 16-in. screen at a distance of about 60 cm. Each configuration of stimuli consisted of a chain of three letters indicating the position (left, right, or central) of the three balls, labeled "A," "B," and "C." The premises offered information about the relative position of the balls, informing directly of the position of some of them, or placing

an "X" in some of the positions. The X symbol indicated that no information was available about the ball occupying that position. For example, an "A X X" premise indicated that Ball A was on the left, but no information was provided for the middle and right balls.

Material. Each premise adds new information to the previous premise (except the noninformative premise "X X X"). Therefore, the final informative premise provides the most complete information. The instructions encouraged participants to pay attention to all the premises and to note that, in spite of the final one being the most informative, in some cases the only informative premise may be the first one (this was the case in the control condition in indeterminate problems). Participants could not predict how many premises would be presented in a trial, or, of course, which condition was being used.

The stimulus set was constructed by changing the name and position of the restrictive ball mentioned in the first premise. Once a particular ball was fixed in the restrictive position in the first premise, two trials were carried out in the experimental condition for indeterminate problems (see example in Table 1). For example, if the first premise indicated that Ball C was not on the right, the second premise might indicate in one trial that Ball C was on the left, and in another trial that it was in the middle. The third premise was formed by adding a new label (e.g., the letter B) to the position occupied by one of the Xs in the first premise (the one not referred to by the second premise). The control condition for indeterminate problems was established by eliminating the information offered by the second premise; thus the noninformative premise "X X X" was presented. In the indeterminate problems, the possible conclusion was constructed by repeating the position and name of the ball mentioned in the second premise. The impossible conclusion was formed by repeating the ball and the position mentioned in the restrictive premise (first premise). In the determinate problems, the possible conclusion was constructed by repeating the labels and positions of the two balls mentioned in the third premise. Two types of impossible conclusion were constructed for this condition: In the first, the position of the ball mentioned in the second premise was maintained, whereas in the second it was changed.

Procedure. The session began with the reading of the instructions informing participants about the nature of the task. These instructions provided an example corresponding to each of the experimental conditions. Participants then carried out two blocks of practice tests before beginning the experimental block of tests. In 24 training tests, each premise remained on the screen for 2 sec. Participants identified aloud the most informative premise. When they made a mistake, the experimenter gave feedback indicating the correct premise. Once the most informative premise was identified, participants pressed the appropriate key. The word "ERROR" appeared on the screen when the incorrect key was pressed. Feedback about errors was given only in this practice block; the objective of this

feedback was to facilitate correct identification of the premise's meaning. In the second block, eight trials were presented with the same time parameters as in the experimental block. In the experimental block, premises were presented successively for 1 sec each (Figure 1). The conclusion was displayed, followed by the question: "Is it possible?" This remained on the screen until the response was given. The response was made by pressing the keys labeled "yes" and "no." Each test began when the participant pressed the space bar. The experimental block consisted of 128 experimental trials presented in random order. Half of these were indeterminate trials and the other half were determinate trials. The content of the premises determined the possible and impossible conclusions (true and false), leading to two types of trial. In half of the trials the correct answer was "yes," and in the other half it was "no." Adhesive labels with the words "yes" and "no" were stuck on the "F" and "T" keys of the keyboard, respectively, in one order for half the participants and in the other order for the rest.

Results and Discussion

Errors accounted for less than 6% of the overall responses. Reaction times shorter or longer than 3 *SD*, calculated for each individual participant, were eliminated. An analysis of variance (ANOVA) was carried out on the reaction time for correct responses for the following factors: determination (determinate vs. indeterminate problem) $\times$ condition (control or experimental) $\times$ conclusion (possible or impossible). Response times should depend on the number of models and also on the particular models derived in each problem. In accordance with the mental model prediction, evaluation time in the determinate problems (one-model problems) was shorter than in the indeterminate problems (two-model problems) [$F(1,31) = 31.43, MS_e = 165,335, p < .001$] (Table 2).

All the problems were predicted to induce possible models except for the control condition in the indeterminate problems. Results agreed with the prediction: Overall, possible conclusions were evaluated more quickly than impossible conclusions [$F(1,31) = 9.20, MS_e = 76,018, p < .01$]. However, indeterminate problems did not show this difference [$F(1,31) = 1.5, MS_e = 95,509, p > .1$].

In accordance with the final prediction, response times were longer in the control condition [$F(1,31) = 10.04, MS_e = 89,841, p < .01$] but again only for determinate problems [$F(1,31) = 29.2, MS_e = 22,382, p < .0001$].

Table 2
Evaluation Times (ETs, in Milliseconds) and Standard Deviations for the Experimental Conditions in Experiments 1 (Evaluation of Sufficiency) and 2 (Evaluation of Necessity): Number of Premises (Two or Three), Condition (Control or Experimental), and Possibility (Possible or Impossible)

	Problem							
	Indeterminate				Determinate			
	Control		Experimental		Control		Facilitation	
	ET	SD	ET	SD	ET	SD	ET	SD
Experiment 1: Evaluation of Sufficiency								
Possible	2,078	850.4	1,732	630.4	1,478	416.7	1,415	391.7
Impossible	1,741	488.4	1,955	522.6	1,826	613.0	1,640	485.7
Experiment 2: Evaluation of Necessity								
Possible	1,539	661.6	1,713	1,112.1	1,054	423.9	933	249.1
Impossible	1,363	482.4	1,406	492.8	1,211	415.7	1,123	314.9

The analysis of the interaction between the three factors [$F(1,31) = 35.8$, $MS_e = 55,816$, $p < .0001$] showed different patterns for indeterminate problems and determinate ones. The results for the indeterminate problems are consistent with the construction of two different models in each of the two conditions: In the control condition, two impossible models were constructed, and the four possible ones were not. The opposite occurred in the experimental condition, where two possible models were constructed, and the four impossible ones were not. This may explain the quicker evaluation of the impossible conclusions for the first case and the possible conclusion for the second case [$F(1,31) = 49.3$, $MS_e = 5,900$, $p < .00001$]. No other differences were found between the two conditions.

Determinate problems lead to the construction of possible models, and therefore responses to possible conclusions were faster than those to impossible ones [$F(1,31) = 11.8$, $MS_e = 25,215$, $p < .01$]. Confirming the final prediction, reaction times were faster for the facilitated condition than for the control condition [$F(1,31) = 63.8$, $MS_e = 98,919$, $p < .0001$] because only in the facilitated condition could the second premise anticipate the construction of the model to be evaluated. No interaction was obtained between the two factors [$F(1,31) < 1$, $MS_e = 44,818$].

In conclusion: (1) Participants evaluated possible configurations more quickly with one-model problems (determinate problems) than with multiple-model problems (indeterminate problems). (2) Only the presence of an ambiguous premise, congruent with two models, facilitated the subsequent evaluation of one of these models.

EXPERIMENT 2

Evaluation of Necessity

The results of Experiment 1 fit the predictions of the mental model theory. In accordance with the model theory, results with reaction time measures were obtained by simplifying the deductive task, making it into an evaluation of sufficiency task. We assumed that the effect of the facilitation in determinate problems resulting from our manipulation of determinate versus indeterminate problems would occur during the comprehension stage. The same main effects should be obtained with the evaluation of necessity, since the two tasks share a common first stage of comprehension. In fact, the only difference between the two tasks is found in the third stage, validation. According to the mental model theory, the evaluation of the necessity of an argument is carried out after previous evaluation of its possibility. Thus, participants would decide whether (1) the configuration is possible, and (2) there is no other possible configuration (Bell & Johnson-Laird, 1998).

For this theory (Johnson-Laird, 1999), an inference is valid if the conclusion holds in any situation congruent with the premises. Consequently, the algorithm consists of a procedure in which a decision is carried out: A conclusion is valid if it holds in all the models of the premises

and is invalid in all other cases. A conclusion is maintained if no situation in which that conclusion is false is derived from the premises. In an evaluation task, the model deriving from the conclusion should be maintained in all the models of the premises.

In the present experiment, the evaluation of the necessity of a conclusion was quite simple: If there is more than one possible model deriving from the premises (indeterminate problems), the model of the conclusion cannot be the only possible conclusion, and therefore the expected answer will be "no." Otherwise, it will be "yes." In this experiment, the task consists of evaluating whether a configuration is the only possible conclusion considering the information provided by the premises. Thus, determinate problems should be resolved in the same way in evaluation of sufficiency and evaluation of necessity tasks, since the possible conclusion is the only possible conclusion, and thus predictions were basically the same for this experiment as for the previous one. However, the same does not apply in the case of indeterminate problems: The predictions were similar to those described in Experiment 1, but with the exception of some conditions. Contrary to the case of Experiment 1, in this experiment the predicted response to the evaluation of necessity for any indeterminate problem was always "no." When the conclusion was possible, participants would note that there was a second alternative configuration, and that the correct answer was therefore "no." When the conclusion was impossible, the answer to the necessity question would be consistent with the answer to the possibility question, and the conclusion arrangement would be different from either of the two possible models deriving from the premises, so that the response would be quicker than when the conclusion was possible.

Method

Participants. Thirty-eight members of the same population as in Experiment 1 participated.

Material. The method was the same as in Experiment 1, but with the addition of a group of filler tests to avoid two-premise problems always having a negative response. Thirty-two filler tests were inserted among the 160 experimental tests at different points distributed throughout the session. In each test the question was, "Is it necessarily true?" instead of "Is it possible?"

Procedure. The procedure was the same as in Experiment 1 (see Figure 1) with the following exceptions: The experimental block consisted of 160 experimental trials and 32 filler trials. In the experimental block, each premise was presented for 2 sec, one after the other. Following the results of a pilot study, the time was increased in order to obtain a similar proportion of correct responses to that obtained in Experiment 1.

Results and Discussion

The error percentage was 6.25% for the overall data. The same criterion was applied as in Experiment 1 for the elimination of extremely high and low reaction times. An ANOVA was carried out on reaction time with the following factors: determination (determinate or indeterminate problems) $\times$ condition (control or experimental) $\times$ conclusion (possible or impossible). Although it was an

Table 3
Evaluation Times (ETs, in Milliseconds) and Standard Deviations for the Experimental Conditions in Experiment 3: Expectation Congruence (Congruent and Incongruent), Possibility of the Conclusion (Possible and Impossible), and Condition (Two Models, One Control Model, and One Facilitated Model)

		Determinate					
		Indeterminate		Control		Facilitation	
		ET	SD	ET	SD	ET	SD
Incongruent Prime							
Possible	1,053	289.0	1,017	288.0	976	274.6	
Impossible	1,078	274.2	1,122	295.9	1,107	307.3	
Congruent Prime							
Possible	997	292.2	941	240.8	935	257.5	
Impossible	1,072	264.3	1,097	272.0	1,069	286.6	

evaluation of necessity task, the last of the variables referred to the possibility of the conclusion (Table 2).

Determinate problems were resolved more quickly than indeterminate ones [$F(1,37) = 37.7$, $MS_e = 364,774$, $p < .0001$]. This difference varied depending on the possibility of the conclusion [$F(1,37) = 17.8$, $MS_e = 184,457$, $p < .001$] and on the condition [$F(1,37) = 12.3$, $MS_e = 70,502$, $p < .01$], as was shown in the analysis of determinate and indeterminate problems. No other differences were significant.

Responses for indeterminate problems, in which “no” was always expected for the evaluation of necessity, were faster for possible conclusions than for impossible ones [$F(1,37) = 4.11$, $MS_e = 109,141$, $p < .05$], and they were faster in the experimental condition than in the control condition. As expected, the slowest responses were for the possible conclusion in the experimental condition (LSD, post hoc analysis). The conclusion was possible but was not the only one, and therefore the expected response was “no.” On the contrary, in the control condition, responses were faster for conclusions congruent with the models of the premises: Impossible conclusions (congruent with one of the two represented models) were more quickly evaluated than were possible conclusions (congruent with one of the four models, presumably not represented in the mind).

For determinate problems, as in Experiment 1, the same effect of facilitation provided by the ambiguous premise was observed. Responses were faster in the facilitated condition than in the control condition [$F(1,37) = 9.9$, $MS_e = 42,138$, $p < .01$]. The evaluation was faster for possible conclusions than for impossible ones [$F(1,37) = 21.7$, $MS_e = 52,958$, $p < .0001$]. As expected, no interaction between the two factors was obtained [$F(1,37) < 1$, $MS_e = 44,426$]. This facilitation effect was obtained in both conditions: for possible conclusions [$F(1,37) = 4.51$, $MS_e = 61,669$, $p < .05$] and for impossible conclusions [$F(1,37) = 5.94$, $MS_e = 24,894$, $p < .05$].

Discussion of Experiments 1 and 2

Participants had to test whether a conclusion was possible (in Experiment 1) or was the only possible conclu-

sion (in Experiment 2) given the information in the premises. In accordance with the main prediction of the mental model theory, in both cases indeterminate (multiple-model) problems were solved more slowly than determinate ones (one-model problems). The task used in these experiments tries to encourage people to represent both possible and impossible configurations from ambiguous descriptions. Thus, the only difference between the two experiments is predicted for the indeterminate problems. In this case, the comprehension of an ambiguous premise, congruent with two of the six possible situations (configurations), should lead to the construction of these two representations (models). If this is true, some results could have been predicted: When a conclusion coincides with one of the two possibilities, the evaluation of sufficiency should lead to a quick response. However, in the evaluation of necessity, in the second experiment participants should have noticed that the possible conclusion was not the only one, and therefore should have responded “no.” These predicted results were obtained: In the first experiment, possible conclusions were evaluated more quickly than impossible conclusions in the experimental condition, and the opposite occurred in the control condition. In the second experiment, the slower condition was the experimental possible condition; that is, when participants knew that a conclusion was possible (since it matched one of their representations) they would realize that another representation was possible.

It should be noted that participants represented the lowest number of models and had no more difficulty representing impossible situations than possible ones, contrary to the principle of truth, which states that only what is true (possible) is represented (not what is impossible). This result is consistent with other studies in propositional reasoning tasks, where the principle of truth did not hold when premises referred to physical situations (Santamaría & Johnson-Laird, 2000), as in our case.

Analysis of the mental model theory about processes of deduction and the relationship between sufficiency and necessity led us to predict similar results in the two experiments for determinate problems. Once again, the results supported these predictions. The second consequence of the construction of multiple representations from the ambiguous premise is that subsequent access to one of those models should be accelerated. This seems to have occurred in both experiments with determinate problems. With determinate problems, the final premise leads to only one possible configuration. However, in the facilitated condition (though not in the control condition), an ambiguous premise congruent with this possibility was presented beforehand. As predicted, the facilitation effect was obtained in Experiments 1 and 2. Responses were faster for the facilitated condition than for the control condition in both experiments. In the facilitated condition, the response to the relevant model derived from the final premise was faster because this model had already been activated by the ambiguous premise.

However, there was a methodological problem in Experiments 1 and 2. The number of models and number of

premises factors were mixed in these two experiments, so determinate problems always corresponded to three-premise problems and indeterminate problems always corresponded to two-premise problems. The differences obtained in response time for determinate and indeterminate problems could be due to the differential difficulty of processing two or three premises. An alternative explanation to that of the number of models would indicate that processing three premises is easier than processing two premises, though we do not think it easy to justify this proposal. All things being equal, it seems plausible that the more premises there are, the harder it is to process them. Nevertheless, to test whether the number of premises could be responsible for the difference, a new experiment was designed to compare determinate and indeterminate problems with the same number of premises.

EXPERIMENT 3

Irrelevant Configurations in the Priming Task

If deduction depends on the construction of mental models, then any manipulation (e.g., priming) that anticipates the construction of those models should speed up deduction. Therefore, if the model theory holds, deduction should be sensitive to priming. In order to test this hypothesis, we tested whether mere exposure to a configuration of three balls prior to the presentation of a problem has any effect on the deductive task, regarding its relation to the premises. If people construct models during the reading of a premise, they should do so more quickly if they already have the model in mind—that is, if the previous configuration is consistent with the premise. The basic task is modified so that all the problems consist of two premises and a conclusion, though at the beginning of each test participants are instructed to ignore a configuration that is shown. Let us give an example of a problem with propositional and schematic descriptions using this new procedure:

The following information should not be kept in mind: Ball C is on the left, Ball B is in the middle, and Ball A is on the right.

Ball C is in the middle.
Ball C is in the middle and Ball A is on the left.

Is the following configuration possible?

Ball A is on the left, Ball C is in the middle, and Ball B is on the right.

The schematic presentation of this problem in the experiment was as follows:

C B A (irrelevant information)
– C – (first premise)
A C – (second premise)

Is this possible?

A C B (conclusion)

Before the beginning of each trial, a configuration in a different color from the rest of the stimuli was displayed

on the screen. Instructions specified that this information had to be ignored to do the task. We call this an “expectation” arrangement because we predict that the model deriving from it will affect the task in spite of the instructions about its irrelevance. For the purpose of simplifying the task, and to correct some potential methodological problems, the restrictive premise was eliminated (the first premise in Experiments 1 and 2). Since no information about the impossible configurations were given by the premises, the task should lead to a general tendency to consider only the possible configurations, in contrast to the previous experiments. For the same reason, only predictions about possible conclusions could be formulated.

Our main objective in Experiment 3 was to test whether mere exposure is sufficient to create a mental model that affects the evaluation task in the way predicted by the mental model theory. A facilitation (priming) effect was expected from the model of the irrelevant arrangement (model expectation), but only when it was appropriate for the models of the premises. In this experiment we also used ambiguous premises—that is, premises consistent with two mental models. As was predicted in the previous experiments, if the understanding of these premises leads to the construction of two mental models, the evaluation of a conclusion consistent with one of these models will be facilitated. Once again, it was predicted that determinate (one-model) problems would be easier than indeterminate (multiple-model) problems.

Method

Participants. Thirty-four students from the same population as those in Experiment 1 participated.

Stimuli and Apparatus. The stimuli and apparatus were identical to those used in Experiment 1, with the following exception: All the stimuli were shown in black, with the exception of the irrelevant arrangement (expectation arrangement), which was presented in red. In this experiment there was no restrictive information.

Material. Each trial consisted of four stimuli: an expectation arrangement, two premises, and a conclusion arrangement. In addition, the expectation (information that should not be considered) could be congruent or incongruent with the premises. For example, the expectation “A B C” is congruent with the premise “– B C” but incongruent with the premise “– A B.” The construction of the problems was the same as in Experiment 1, except for the addition of the expectation, which was made using the same conclusion arrangement in half the problems (congruent expectation–possible conclusion and incongruent expectation–impossible conclusion) and a different one in the other two conditions (congruent expectation–impossible conclusion and incongruent expectation–possible conclusion). Determinate and indeterminate problems had the same number of premises.

Procedure. The procedure was the same as in Experiment 1 with the following exceptions: Instructions encouraged participants not to consider the irrelevant information shown in red at the beginning of each trial. This expectation arrangement, presented in the center of the screen, served as an ocular fixation point for a period of 1,500 msec. It then disappeared and, with equal spatiotemporal parameters, as in Experiment 1, there followed the sequence of two premises and the conclusion.

The experiment consisted of 216 experimental trials. One third were indeterminate problems, with an informative premise shown in the first position in half the trials and in the second position in the other half. Another third of the experimental trials constituted the

determinate control condition, and the final third constituted the determinate facilitated condition. Half the problems had a congruent expectation and the other half had an incongruent expectation. Likewise, half had a possible conclusion and the other half had an impossible conclusion.

Results

The percentage of errors was less than 5% of the overall data. The procedure of elimination of extreme data for the analysis was the same as that used in Experiments 1 and 2. An ANOVA was carried out with the following factors: expectation (congruent or incongruent) $\times$ condition (indeterminate, determinate-control, or determinate-facilitated problems) $\times$ conclusion (possible or impossible). When the expectation was congruent, the evaluation was faster than when it was incongruent [$F(1,33) = 20.78$, $MS_e = 7,906$, $p < .0001$]. Possible conclusions were evaluated more quickly than were impossible conclusions [$F(1,33) = 43.69$, $MS_e = 25,353$, $p < .0001$]. The condition had a different effect for possible and impossible conclusions [$F(2,66) = 7.12$, $MS_e = 10,613$, $p < .01$]: The effect of condition was reliable only for possible conclusions [$F(2,66) = 7.44$, $MS_e = 11,454$, $p < .01$] and not for impossible ones [$F(2,66) = 1.36$, $MS_e = 14,993$, $p > .1$] (Table 3).

The same predictions as in the previous experiment were confirmed. The analysis of possible conclusions showed that their evaluations were faster in determinate problems than in indeterminate ones [$F(1,33) = 9.17$, $MS_e = 151,471$, $p < .01$]. Moreover, in determinate problems the facilitated condition produced quicker problem solving than did the control condition, though this difference did not reach statistical significance [$F(1,33) = 2.98$, $MS_e = 19,048$, $p = .09$]. The lack of significance is due to the fact that only when the expectation was incongruent was this difference significant [$F(1,33) = 4.16$, $MS_e = 28,370$, $p < .05$], and not when it was congruent [$F(1,33) < 1$, $MS_e = 4,272$]. Thus, results for the irrelevant expectation condition are consistent with the results of Experiments 1 and 2, where no expectation was manipulated, and therefore no relevant representation could be constructed. However, in the relevant expectation condition the representation given by the expectation is constructed at the beginning, and therefore the control condition was facilitated as much as the facilitated condition.

An additional analysis showed that conclusions were evaluated faster when expectations were consistent with premises [$F(1,33) = 43.7$, $MS_e = 1,846$, $p < .0001$], but not when expectations and conclusions were the same [$F(1,33) = 2.15$, $MS_e = 4,879$, $p > .1$]. The position of the informative premise in the indeterminate problems had no effect.

Discussion of Experiment 3

The main result in Experiment 3 was the priming effect. That is, the previous perception of a task-irrelevant premise affected participants' performance even when instructions encouraged them not to consider that information. When

the information as congruent with the premises, a priming effect was observed.

Premises in this experiment led participants to consider only possible, not impossible, information, unlike those in Experiments 1 and 2, and therefore only possible conclusions permit us to test the predicted models constructed. Analysis of the evaluation of possible conclusions showed a replication of the results of Experiments 1 and 2.

On the one hand, the evaluation of a possible conclusion was faster in determinate problems than in indeterminate problems. In all the experiments we tried to make complete configurations of three balls as the content of the models. Note that results run counter to an alternative explanation in which participants do not represent complete configurations and simply apply a strategy matching letter by letter. For example, given the premise "A C -," people could represent just "the letters A and C" instead of "A C and B." The contrast in the control condition between determinate and indeterminate problems discounts this explanation: The number of letters in the informative premise for the determinate problem was greater than for the indeterminate one, and therefore, using a matching interpretation, longer response times would be expected in the former condition. In fact, the opposite occurred (as in Experiments 1 and 2), as we have assumed, since one model is required in the first case but two are required in the second. Response times were longer for the indeterminate than for the determinate problems.

Moreover, the facilitation effect in the determinate problems was also replicated. An ambiguous premise (leading to two possibilities) displayed before the determinate premise (leading only to one of those possibilities) reduces evaluation time of the conclusion. As predicted, the previous access to the relevant representation accelerated the response. In Experiment 3, this reduction of the evaluation time was also obtained with the congruent expectation by means of a priming effect. When the expectation was congruent with the premises, no significant differences were obtained when the ambiguous premise was present (the relevant representation had already been accessed).

GENERAL DISCUSSION AND CONCLUSION

The priming effect is commonly used for studying the presence and the activation or inhibition of mental representation in cognitive psychology. Our aim with these three experiments was to test a specific part of the algorithm proposed by the mental model theory: whether mental representations are activated and affect the evaluation of sufficiency and necessity of a conclusion, and whether this evaluation can be primed. In this study, a task easier than traditional tasks was used to allow sufficient observations for reaction time to be recorded. The procedure simplifies all the components of deduction: (1) Premises give diagrammatic information instead of propositional information; (2) the maximum number of models is six, and

premises give information reducing the possibilities; (3) no integration of premise information is required; and (4) participants must evaluate the sufficiency (Experiments 1 and 3) or the necessity (Experiment 2) of a conclusion. Results fit the model theory predictions. First, when premises led to one possibility (one-model problems), the evaluation was faster than when they led to multiple possibilities (multiple-model problems). This difference between determinate and indeterminate problems is a basic prediction of the mental model theory. Second, there is a critical comparison between the two conditions in the determinate problems. In both conditions the final premise led to one possibility, but only in the experimental condition were participants shown a previous ambiguous premise consistent with that possibility. The acceleration of the response in the experimental condition relative to the control condition is consistent with the activation of the relevant "model." This result is similar to the so-called priming effect. In Experiment 3 a new way to test priming was used in addition to the previous one. In this experiment, participants were presented with a premise they were instructed to ignore, which affected the way they dealt with the problem. This result is consistent with the activation of a model (a representation of an arrangement) by the irrelevant premise that primed the access to this model when it was required. We refer to this activation of a model as "expectation."

Thus, two different kinds of facilitation are shown in this study. In the first kind, evident in all three experiments, an ambiguous arrangement led to the construction of alternative models, facilitating the construction or evaluation of a configuration that would coincide with one of these models. This kind of facilitation could be related to the understanding of certain linguistic expressions (e.g., counterfactual vs. factual conditionals; see Byrne & Tasso, 1999) and spatial descriptions (indeterminate vs. determinate descriptions; Byrne & Johnson-Laird, 1989) that leads to the construction of multiple models. The source of the second type of facilitation is the creation of an expectation due to the previous presence of a stimulus. This new priming effect is shown in Experiment 3. The effect of the mere exposure of the information could be related to two phenomena in deductive reasoning: "matching bias" (Evans, 1998; Evans & Lynch, 1973) and focusing (proposed by Legrenzi, Girotto, & Johnson-Laird, 1993). On the one hand, participants are more likely to regard as relevant those cases in which there is a match between elements referred to in the statements. For example, the conditional statement "If a card has an 'A' on one side, then it has a '4' on the other side," referring to four cards (A, D, 4, and 7), leads participants to consider for further analysis the "A" and "4" cards, because they are seen as more relevant than the other cards.

Furthermore, Girotto, Mazzocco, and Tasso (1997) confirmed the focusing prediction when they demonstrated that changing the order of presentation of premises in a conditional inference task affects results. This was explained by the fact that the anticipated exposure of a premise leads

people to focus on a different mental model from the one focused on if the traditional order of presentation is used. With the latter model, reasoners integrate or discard information taken from later premises. Although the two sources of facilitation are different, they may have the same effect: The processing is facilitated when the same or related information is shown previously.

How can these results be related to theories of deduction? First, neither rule nor model theories were constructed to cope with this kind of task. The closest example of a rule theory is Hager's (1984). However, no priming effect can be clearly predicted from this theory. Although priming is not necessarily contrary to the predictions of the rule theories, the modulation of this effect in deduction deserves an explanation in terms of the mental representations involved in deduction. An algorithmic description of a rule theory of deduction with diagrammatic premises should incorporate a mechanism for priming.

Second, in the first stage of Evans's heuristic-analytic theory (Evans, 1984, 1989), in a deductive task only part of the information initially processed proceeds to the posterior analytic stage. The heuristic-analytic theory holds that the information that passes through the filter is that which is relevant. In our view, much of the explanatory power of this theory lies in its capacity to disentangle the concepts of attended information and information relevant to the task. Roberts (1998a, 1998b) criticized the circular definition of the two concepts in the theory. On the one hand, the attended information is what is relevant for the task, and therefore relevance is the decisive factor in deciding what will be processed. On the other hand, what is attended becomes relevant, although it would be irrelevant for the task. If this is true, relevance would not be a determining factor for selecting the information that continues through the filter to the analytic stage. A way of disentangling attention and relevance is to focus participants' attention on stimulation that is not—a priori—relevant for the task, and to analyze its effect in a deductive task. If it is the relevance (of the task) that determines selection of the information that passes the filter, the manipulation effect should be null. However, participants could represent the information present in the environment regardless of whether it is relevant or irrelevant to the task. In this case, when the model is congruent with the premise information the deductive task would be facilitated, and the opposite would occur when the model is incongruent with the premise information. This is what happened in Experiment 3: Even when information was not relevant for the task, that information could affect it. Of course, this does not mean that the theory is incorrect, or that the information irrelevant to the task will be central to the action of the task. It merely means that in some circumstances, the information present in the situation where an inference is made may facilitate a deductive task, even when that information is irrelevant to the deductive task. In short, what we represent affects the way we make deductions. This is clearly in line with the mental model theory.

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