# Deductive Reasoning in Right-Brain Damaged

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**Abstract**

Deduction is a high level cognitive ability which has not been much analyzed in neuropsychology. Cognitive psychologists and cognitive scientists strongly debate the nature of the mental processes involved in deductive reasoning. A theory particularly pertinent to the neuropsychology of thinking is Mental Model Theory, which postulates the use of analogical representations in reasoning. Studies on unilateral neglect in neuropsychology show that the right hemisphere is involved in analogical representations. On these theoretical bases we make a critical prediction about the role of the right hemisphere in reasoning. This paper investigates the ability of right-brain damaged patients to deal with two main sorts of deduction: syllogistic and relational reasoning. Our results suggest a significant involvement of the right hemisphere in reasoning. Also, as far as syllogistic reasoning is concerned, the results allow for the existence of a verbal component, beside the analogical one.

## 1. Introduction

Deductive ability is the human capacity to draw conclusions from premises, depending on their form. A valid deduction is one where the conclusion is true given that the premises are true. In this paper we focus on two sorts of deduction, relational and syllogistic reasoning.

We investigate relational reasoning through three-term series problems. They consist of two premises and a conclusion; each premise refers to two terms linked by a transitive relation. One term is shared by the premises and allows to draw a conclusion concerning the relation between the other terms. An example is the problem:

[1] Ann is taller than Bob
Bob is taller than Carl
--------------------------------------------
Therefore, Ann is taller than Carl

Syllogistic reasoning consists in drawing a conclusion from couples of quantified premises. Each premise can have the following forms: universal affirmative (All of the x are y), particular affirmative (Some of the x are y), universal negative (None of the x is a y), and particular negative (Some of the x are not y). An example is the syllogism:

[2] All the architects are bakers
None of the bakers is a chemist
--------------------------------------------
Therefore, none of the architects is a chemist

The two premises share a common term, the so-called 'middle' term B - and they can have four different arrangements (or 'figures') of their terms: AB-BC, BA-CB, AB-CB, and BA-BC.

Recent researches in neuropsychology argue that a damage to the right hemisphere impairs patients' ability to make deductions. In a study on conditional reasoning, Whitaker *et al.* (1991) and Savary *et al.* (1992) found that right-brain damaged patients (hereafter, right-patients) were poorer than left-hemisphere damaged at reasoning from false conditional premises; in particular, they were unable to draw inferences independently on their world knowledge. Thus, the authors claim that the right hemisphere is responsible for reasoning deductively, that is independently on the content of the problem. Caramazza *et al.* (1976) have shown that right-patients have problems even in deducing the converse of relations in problems of the following kind:

[3] John is taller than Bill
Who is shorter?

In line with this result, Read (1981) carried out a study on right patients and concludes that they are impaired with three-term series problems such as [1].

Deglin and Kinsbourne (1996), in contrast with the previous studies, claim that people reason logically under right hemisphere suppression, and they reason empirically (especially for familiar content) under left hemisphere suppression. Thus, the authors claim that the left hemisphere is responsible for reasoning deductively.

In order to bring new evidence on this issue, we devised a new experiment to more deeply investigate right-patients ability to reason deductively.

In Section 2 we shall briefly present the main cognitive theories of deduction. In Section 3 we present our experiment, and the results. Discussion and conclusions are in Section 4.

## 2. Cognitive Theories of Deduction

Cognitive scientists have proposed three main classes of theory about deduction:

1. Rules of inference, either formal rules (Braine & Rumain, 1983; Rips, 1994) or content-specific rules (Bar-Hillel, 1967; Clark, 1969).
2. Verbal processes, such as encoding and decoding of the verbal information given in a problem's premises (Polk & Newell, 1995).

3. Analogical representations, constructed and manipulated by semantic procedures (e.g. De Soto, London & Handel, 1965).

The latter approach, unlike the others, assumes that the major component of reasoning is nonverbal. In its perspective, deduction has nothing to do with constructing chains of inference using mental rules (see theories in 1). Further, the analogical approach claims that language comprehension and generation do not account for the entire range of deductive phenomena (see theories in 2). Deductive reasoning is considered a semantic, rather than syntactic process: it involves construction of analogical representations in some cognitive space. The actual mental representations may take the form of Euler circles (Erickson, 1974; Ford, 1994; Stenning & Oberlander, 1995). Alternatively, they could be mental models (Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991).

The tenets of the analogical approach, together with earlier neuropsychological data, provide a major prediction. If it is true that the manipulation of analogic representations depends on the right hemisphere, as some neuropsychological studies on unilateral neglect and visual imagery suggest (e.g., Bisiach & Luzzatti, 1978; Farah, 1984), then patients with right hemisphere damage should find it hard both to reason about abstract matters and to reason about topics that are easy to visualize. Our aim is to test this prediction.

We shall follow the tenets of Mental Model Theory (MMT: Johnson-Laird, 1983; Johnson-Laird & Byrne, 1991), as it is the only proposal inside the analogic paradigm to account for both syllogistic and relational reasoning. Hence, we assume that reasoning consists in constructing and manipulating mental models. A model is a representation with a structure corresponding to the structure of the state of affairs it represents.

A theory of deductive reasoning ought to explain two main phenomena: (a) some problems are easier than others; (b) there exist consistent patterns of errors, commonly drawn by the reasoners. MMT accounts for the two phenomena. We illustrate the theory on the syllogistic domain (cfr. Bucciarelli & Johnson-Laird, 1998), but the same procedures also apply to the relational domain. Consider, for instance, the syllogism:

[4] All of the architects are bankers
None of the bankers is a chemist
-----------------------------------------------
None of the architects is a chemist

MMT claims that the reasoner starts by constructing a mental model for each premise (*construction phase*). The state of affairs described by the first premise in [4] is analogically represented by the model:

```
[architect]   banker
[architect]   banker
```

where each line corresponds to an individual. The mental footnote denoted by the square brackets - denotes that the set of architects has been represented in its entirety. Hence, if new entities are introduced into the model, they cannot be architects. The second premise has a model of the form:

```
[banker]   -chemist
[banker]   -chemist
           [chemist]
           [chemist]
```

The model explicitly represents the bankers as not chemists. The second step in the reasoning process is the integration of the models of the premises in a single representation, by overlapping the items identical in the two models (*integration phase*). In our example, the integration produces the model:

```
[architect]   [banker]   -chemist
[architect]   [banker]   -chemist
                         [chemist]
                         [chemist]
```

The model supports the putative conclusion 'None of the architects is a chemist', or *viceversa*. In fact, the conclusion could be erroneous; it could be possible to find an alternative model of the premises where the conclusion does not hold. Thus, an exhaustive search for all possible integrated models of the premises guarantees from erroneous conclusions (*falsification phase*). However, in syllogism [4] falsification produces no alternative models of the premises, and the initial putative conclusion can be correctly drawn. Now consider syllogism [5].

[5] None of the aviators is a baker
Some of the bakers are contortionists
-------------------------------------------------------
Some of the contortionists are not aviator

The model of the first premise is:

```
[aviator]   -baker
[aviator]   -baker
            [baker]
            [baker]
```

The model of the second premise is:

```
baker   contortionist
baker
        contortionist
```

It represents three sorts of individual: one baker and contortionist, one baker, one contortionist. A first integration of the models of the premises yields the following model:

| | | |
|---|---|---|
| [aviator] | -baker | |
| [aviator] | -baker | |
| | [baker] | contortionist |
| | [baker] | |
| | | contortionist |

which supports the putative conclusion 'None of the aviators is a contortionist', or *viceversa*. If falsification is not attempted, such a conclusion is erroneously drawn. In fact, falsification would produce the following model:

| | | |
|---|---|---|
| [aviator] | -baker | contortionist |
| [aviator] | -baker | |
| | [baker] | contortionist |
| | [baker] | |
| | | contortionist |

where the putative conclusion does not hold. The model supports the conclusion 'Some of the aviators are not contortionist'. As a matter of fact, falsification produces also the following model:

| | | |
|---|---|---|
| [aviator] | -baker | contortionist |
| [aviator] | -baker | contortionist |
| | [baker] | contortionist |
| | [baker] | |
| | | contortionist |

The correct conclusion is the one that holds in all the possible integrated models of the premises, namely 'Some of the contortionists are not aviator'. So, in order to draw the correct conclusion it is necessary to produce all the possible integrated models.

To sum up, MMT claims that people are able to reason deductively because they construct and manipulate the analogical representations of the premises. The theory predicts that problems' difficulty depends on the number of models that the reasoner has to construct: the greater is the number of models, the harder is the problem. Thus, MMT predicts that problem [5], that requires construction of two models is more difficult than problem [4], that requires construction of one model. Further, MMT explains and predicts both correct and erroneous responses. Correct responses are based on all the possible integrated models of the premises, whereas the erroneous responses are based on a subset. Thus, for syllogism [5] MMT predicts the erroneous response 'None of the aviators is a contortionist' (or *viceversa*), and 'Some of the aviators are not contortionist'.

According to the theory, the amount of working memory necessary to draw a conclusion is a cognitive resource that influences the reasoning process. In particular, as models are analogical representations, and analogical representations have spatial features, the ability to manipulate models should correlate with the spatial working memory capacity.

Our experiment (Section 3) was devised to test the following hypotheses:

1. Deductive reasoning is impaired in right-patients, as the analogical theories predict.

2. MMT's predictions about problems' difficulty and erroneous responses hold for right-patients.

3. Our further aim was to explore possible correlations between the ability to solve deductive problems and the measures provided by two neuropsychological tests, in particular the measure of the spatial working memory capacity.

## 3. The Experiment

### Participants

Thirty-four right-handed patients with right unilateral cerebral lesion revealed by CT scan participated in the experiment. Fourteen of them were ruled out because they did not understand the requirements of the experimental tasks; twenty patients are left (5 women and 15 men). Their ages ranges from 42 to 84 years (mean age = 60.6; sd = 13.2 years), their school attendance ranges from 5 to 19 years (mean = 9.3; sd = 4.6).

The control group consists of twenty participants (12 women and 8 men) comparable to the experimental group for both age (mean age = 59.9: sd = 10,9) and years of school attendance (mean = 9.6; sd = 3.6)

We have excluded from the two groups the participants with intellectual impairments, as revealed by the Mini Mental State (i.e., score below 25/30), and the right-patients with impairment in verbal comprehension, as revealed by the Token Test (i.e., score below 30/36).

### Design and Material

The experiment consists of three sorts of tasks: deductive reasoning tasks, paraphrases tasks and neuropsychological tests. The paraphrases tasks were introduced to test the ability to infer the converse of relations such as 'Ann is shorter than Ben' (i.e., 'Ben is taller than Ann'), as well as the converse of quantified assertions like 'All of the painters are musicians' (i.e., 'Some of the musicians are painters'). As we said above, some studies suggest that also the ability to deal with paraphrases of this sort would be impaired in right-patients.

**Reasoning Tasks** The tasks consists of 10 syllogisms and 8 relational problems.

The syllogisms are selected among the classical set of 64, and they all have a valid conclusion interrelating the end terms. Five of them are according to MMT one-model problems, and five of them are multiple-model problems. Syllogisms are balanced according to the figure of the premises and the sort of conclusion. Further, the medium term B in the premises refers to an hobby, the end terms A and C refer to jobs. The experimenter reads the syllogistic premises, then he asks the question: 'How many A are C?' or 'How many C are A?', consistently with the direction of the correct conclusion. Subjects are told that possible answers are: 'All...are...'; 'Some...are...'; 'None...is...'; 'Some...are not...'.

The relational problems are three-terms series problems supporting a valid conclusion. All of them are - according to MMT - one-model problems. The premises refer to the relations 'taller than' and 'shorter than'. The relations, as well as the terms, are arranged in the 4 possible ways inside the couple of premises. The experimenter reads the relational premises, then he asks the critical question. In half of the problems the question is 'Who is the tallest between A and C?', and in half of the problems is 'Who is the shorter between A and C?'.

**Paraphrases Tasks** The tasks consist of 10 paraphrases of quantified premises and 8 paraphrases of relational premises. The terms inside each premise refer to a hobby and a job. Each of the premises to paraphrase is presented with another premise of the same sort, i.e. quantified or relational. Thus, the couples of premises are analog to the couples of premises used in the syllogistic and the relational reasoning tasks. The only difference is that in the paraphrases tasks it is not possible to relate the information conveyed by the premises, because they do not share a common term (the figure of the premises is AB-CD). The experimenter reads a couple of premises, and invites the participant to paraphrase the first premise in half of the problems, and the second premise in the other half, in a random order. The reasoner is cued to paraphrase by questions of the following sort: 'How many A are B?' (paraphrases of quantifiers), 'Who is the tallest between A and B?' (paraphrases of relational terms).

**Neuropsychological Tests** We used two tests to depict a general framework of the participants' working memory capacity: Corsi's test and a Word List Learning test.

Corsi's test was adopted to measure the visuo-spatial short-term memory capacity. We followed the standard procedure. The experimenter shows the participant 9 cubes attached on a wooden-board. Then, in a preliminary trial, he touches each cube one at a time, and invites the participant to repeat the same movements. The real test starts in case no errors occur. The experimenter touches cubes in series of increasing length (from 2 up to 10 cubes in a row), and the participant is invited to touch the same cubes in the same sequential order. The participant deals with three different trials for each series; if she succeeds at least in two trials, then the test continues. The visuo-spatial memory span of the participant corresponds to the number of cubes in the longest of the series reproduced, where at least two trials were successful.

A Word List Learning test was used to measure the verbal memory span. The experimenter reads to the participant a list of 10 words, and the participant repeats as many of them as she can remember, in her preferred order. Shortly, the experimenter reads again the 10 words, and the participant is invited to repeat them, trying to enrich the list of the words remembered. The test continues until the participant repeats all the 10 words. The maximum number of repetitions by the experimenter is 20. The score is calculated by taking into account the number of repetitions, age and years of school attendance of the participant. The score in this test is counterintuitive: it increases with the decrease of the performance.

## Procedures

The experiment is carried out in a single session, individually, in a quiet room. The order of presentation of the problems is the same for all the participants. First, the participant deals with the Token Test (only the right-patients) and the Mini Mental State. In case she does not encounter any difficulty, the experiment continues with Corsi's and the Word List Learning tests. Then, the participant deals with the reasoning and the paraphrases tasks. We devised two protocols, where the following factors were balanced: the order of presentation of the reasoning and the paraphrases tasks; the order of presentation of the syllogistic and relational problems inside the reasoning tasks; the order of presentation of the paraphrases of quantifiers and relational terms inside the paraphrases tasks. The tasks are introduced by a warm-up: the experimenter reads a relational problem and invites the participant to draw a conclusion, thus answering the specific question. Further, the participant is invited to consider as true the premises, and to draw a conclusion that is true given that the premises are true.

## Results

**Reasoning and Paraphrases Tasks** As predicted, the performances of the patients are worse than the performances of the control group (see Table 1). The difference is statistically significant for the relational problems (Mann-Whitney test: $z = -2.029$; $p < .05$) and the paraphrases of relations (Mann-Whitney test: $z = -2.056$; $p < .04$). The difference is not statistically significant either for the paraphrases of quantifiers (Mann-Whitney test: $z = -1.43$; $p = .15$), or for the overall syllogisms (Mann-Whitney test: $z = -1.44$; $p = .14$). However, one-model syllogisms are easier for the control group (80% of correct conclusions), than for the patients group (71% of correct conclusions), although the difference is only marginally significant (Mann-Whitney Test: $z = -1.894$; $p = 0.058$). Multiple model syllogisms are hard to solve for all the participants (as MMT predicts); the two groups do not differ in their performances (Mann-Whitney Test: $z = .812$; $p = .075$). In general, we conclude that the results concerning the two tasks confirm prediction 1: deductive reasoning is impaired in right-patients, as the analogical theories predict.

Table 1. Percentages of correct responses in reasoning and paraphrases tasks.

| Tasks | Patients | Control group |
|---|---|---|
| Syllogisms | 35 | 42 |
| Relational problems | 72 | 82 |
| Paraphrases (quantifiers) | 48 | 51 |
| Paraphrases (relational terms) | 68 | 76 |

Prediction 2 is also confirmed: MMT's predictions about problem difficulty and erroneous responses also hold for right-patients. One-model syllogisms are easier to solve than multiple-model syllogisms; the prediction holds for both the patients (71% versus 0%, Wilcoxon Test: $z = -3.62$, $P = 0003$) and the control group (80% versus 4%, Wilcoxon Test: $z = -3.92$, $p < .0001$). Thus, syllogism [4] is easier than syllogism [5], both in the patients (71% versus 0% of correct conclusions) and in the control group (90% versus 0% of correct conclusions). Further, as MMT predicts, the most common erroneous responses are based on a subset of the possible integrated model of the premises. Thus, the common error in dealing with problem [5] is to infer that 'None of the aviators is a contortionist', or *vice-versa* (44% of the errors in right-patients, and 85% in the control group)[1].

**Neuropsychological Tests** The performance of the right-patients was significantly worse than the performance of the control group in Corsi's test (Mann-Whitney test: $z = 4.1$; $p < .0001$), as well as in the Word List Learning test (Mann-Whitney test: $z = -2.86$; $p < .005$). The mean scores obtained by the participants are in Table 2; as the two tests have not, in principle, a maximum score, a benchmark is the best score obtained by the participants. Remember that, in the Word List Learning test, the score increases with the decrease of the performance.

**Correlations Between Tests and Tasks** We explored the possible relations between the performances in the neuropsychological tests and the performances in the tasks through some correlations. For the syllogistic reasoning task, we used only the data concerning one-model syllogisms because multiple model syllogisms were hard to solve even for the control group.

[1] The participants had no chance to draw the erroneous response 'Some of the aviators are not contortionist', which is predicted by MMT, because the cueing question for this syllogism is: 'How many contortionists are aviators?'.

Table 2. Mean scores obtained by the two groups of participants in the neuropsychological tests.

| Neuropsychological Tests | Patients | Control group |
|---|---|---|
| Word List Learning (best score=2.437) | 6.95 | 4.89 |
| Corsi (best score=7) | 3.44 | 5.1 |

As far as the control group is concerned, a good performance in the relational problems correlates with a good performance in both Corsi's (Fisher's $r = .685$; $p < .001$) and Word List Learning (Fisher's $r = -.618$; p.005) tests. Besides, there is a positive correlation between the performance in the paraphrases of relations task and the performance in Corsi's test (Fisher's $r = .531$; $p < .05$).

In the right-patients, we found a single correlation between the performances in the Word List Learning test and the syllogistic reasoning task (Fisher's $r = -.56$; $p < .05$).

As our underlying hypothesis is that both syllogistic and relational reasoning rely on the same mental processes, we also explored the relation between the two sorts of task. As expected, we found a correlation in the right-patients (Fisher's $r = .787$, $p = .0002$) and in the control group (Fisher's $r = .516$, $p = .0186$).

## 4. Discussion and Conclusions

Our results suggest that the right hemisphere plays a major role in deductive reasoning. In particular, right-patients are worse than the control group in reasoning with relational problems and paraphrasing relational premises. These results support the idea that the two tasks involve analogical representations, which are mainly a competence of the right hemisphere. Our results agree with those of some previous studies (see Section 1), and they disagree with the results of Deglin and Kinsbourne (1996). The authors claim that the left hemisphere is responsible for reasoning deductively, but we have two methodological reasons for being skeptical about their results. First, their experimental sample consists of either schizophrenics or manic-depressive psychotics. Second, they use problems with identical content to test the participants in different experimental conditions.

The results concerning the performance of the right-patients and the control group in the syllogistic reasoning task and the paraphrases of quantified assertions task deserve some consideration. In particular, although one model syllogisms are harder to solve for the right-patients than for the control group, multiple-model syllogisms are difficult to solve for all the participants in our experiment. This result confirms MMT's prediction that multiple models problems are difficult to solve. However, the really bad performance of the control group is a genuine surprise. Indeed, in a previous study by Bara, Bucciarelli and Johnson-Laird (1995), adult subjects' percentage of correct responses to the same set of 10 syllogisms was 56% (26% if we consider only the multiple models ones). We suspect that our experimental procedure for syllogisms makes hard the task of drawing an inference, especially for the hardest of the problems. The procedure which consists in reading the couples of syllogistic premises together with the final question 'How many x are y?' - was meant to cue reasoners, especially right-patients, towards the relevant information. However, in order to answer the critical question, the reasoner has to keep in mind the *verbatim* of the premises and the cueing question. We suspect that this task interferes with the reasoning process. The correlations between the verbal memory span and the reasoning tasks would support such an hypothesis. In line with the same argumentation, we observe that also three-term series problems were quite difficult for our control group, whereas it is well known that they are quite easy, and the difference in difficulty among problems is detectable, following the standard procedure, only by positing a time limit to draw the conclusion (see, De Soto *et al.* 1965). Again, our experimental procedure could explain the bad performance of our control group in the relational reasoning task.

An alternative explanation of the results is that the analogical component plays a major role in relational reasoning and paraphrases of relational terms, but the verbal component is as important as the analogical component in reasoning with syllogisms, and in paraphrasing quantifiers. As the performances of the right-patients and the control group in the two tasks considered as a whole do not significantly differ, it is plausible that they involve verbal processes which are mainly a competence of the left hemisphere.

The results of the correlations between the neuropsychological tests and the reasoning and the paraphrases tasks are consistent with the two possible explanations. Further, they confirm the existence of a tight bond between the deductive ability and the spatial working memory capacity, as predicted by MMT.

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