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Solving Natural Syllogisms

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The oldest reasoning task ever studied by psychologists is categorical syllogisms. One may question whether after a century of investigation there is still something to be learned about people's deductive competence from research on syllogistic reasoning. In this chapter this question will receive a double answer: a negative answer as far as the usual laboratory task is concerned, as it will be claimed that it has been deeply misused; but also an affirmative answer in the sense that previous research has ignored the ecological relevance of syllogisms: this has often been denied but it will be argued that this stems from a fallacious conception of the epistemological status of the formal arguments and from a subsequent bias in their instantiation. Finally, it will be shown that lay people are highly competent and successful in using syllogisms once a methodological precaution has been taken, which turns the arguments into *natural syllogisms* satisfying the demand of ecological validity.

NATURAL SYLLOGISMS AND THE STATUS OF FORMAL SYLLOGISMS

Surprisingly, there seems to be little reflexion in the psychological literature on the nature of the knowledge or competence that is revealed by participants' performance on the common syllogistic task. With the possible exception of the "rational analysis" (Anderson, 1990) based on the distinction between a computational level and an algorithmic level, researchers seem to be little concerned with the epistemological status of the formal arguments (or of their instantiations) presented to the participants. To illustrate what is meant, consider the following joke. Two persons come across a barking dog. One of them says: "Beware ! This dog is barking". The other one replies: "Never mind, you know that when a dog is barking, it never bites". Then the first one says: "OK, I know this, but does the dog know it too?"

Asking participants to solve a formal syllogism amounts to asking them to access the formal language of the theoretical model and to draw inferences within this model, that is, to behave like logicians who have formal knowledge (like the character who *knows* that the dog does not bite). The treatment of the

formal argument is situated at a level of cognition that differs from that of the individuals outside the laboratory who (like the dog *unaware* that it does not bite) draw a conclusion from the categorical relations that they currently entertain in working memory. The arguments that reasoners actually process are less constrained than those used in the laboratory, which are abstractions that underlie reasoners' actual arguments. Classical syllogisms constitute an idealisation that goes beyond the arguments observable in daily life, which we will call *natural syllogisms*. The latter may differ from the former by a number of superficial features such as the order of the premises, the place of the conclusion, their insertion in a dialogue; more important, they differ by the existence of a premise that contains a relation of category inclusion retrieved from long term memory (but is absent in their typical enthymematic realisations). This feature is crucial and will be considered in detail below.

To put it yet otherwise, solving syllogisms of the type used in the laboratory requires a level of abstraction that it would be necessary for the individuals to reach in order to formulate the *formal* argument that they would have to produce, should they be asked to justify their *informal* natural argument. To this extent, the laboratory task is a metacognitive task that tests participants' awareness of the rules that guide their own inferential production outside the laboratory.

From the foregoing considerations it follows that, for a century, research on syllogistic reasoning has been deeply misdirected: instead of considering natural arguments it has focused on formal artificial arguments that have no ecological validity. If the laboratory task is of any interest to the investigation of reasoning, this is only to the extent that it helps reveal the variety of strategies that people use to solve deductive arguments, the majority of which escape their knowledge and capabilities. In the present chapter, little reference will be made to the considerable literature and the main theories that concern the laboratory task. However, as an aside, it will be shown that one of the main strategies used by participants to solve the laboratory task is but an application of the way natural syllogisms are solved. A method of proof that dates back to Aristotle, called *ecthesis*, and a recent logical analysis of syllogisms will be

brought together and shown to yield essentially the same procedure. Then, the bulk of the chapter will be devoted to showing that the procedure in question is automatically involved while processing natural syllogisms. This leads one to the prediction that near perfect performance is to be expected on natural syllogisms, a prediction that will be shown to be experimentally supported.

ARISTOTLE'S PROOF BY ECTHESIS

Two methods of proof used by Aristotle are well-known. Four "perfect syllogisms" with a status akin to axioms of the system are first identified (namely, AAA-1, AII-1, EAE-1, and EIO-1; see the Appendix for the designation of the syllogisms). The first method is applicable to all the other syllogisms but two. It consists in turning the syllogism under consideration into a perfect one by the conversion of one or both premises, or by changing the order of the premises. The second method, which consists of a *reductio ad impossibile*, is applied to the remaining two syllogisms, after which there is no need for another kind of proof. However, Aristotle described another method, called *ecthesis* (or proof by exposition). Here is an example given by Aristotle in the *Analytica Priora* (6, 28a) to prove AAI-3 (*all M are P; all M are S / some S are P*; the reader is reminded that a sentence such as *all M are P* is formulated as *P belongs to every M*): "if both P and S belong to every M, should one of the M, e.g. N, be taken, both P and S will belong to this, and thus P will belong to some S" (Barnes edition, 1984, Vol. 1, p. 46), a more common formulation of which would be "if all M are both P and S, should one of the M, e.g. N, be taken, this will be both P and S, and thus some S will be P". There have been discussions among logicians and historians of logic about the logical type of the exposed entity, N. Some (Lukasiewicz, 1957; Patzig, 1968) have proposed that it is a category common to the subject and the predicate (or to the subject and the negated predicate) of a particular sentence. This view has some technical difficulties and the more recent analyses offered by Lear (1980), Mignucci (1991), Smiley (1993), Smith (1982) and Thom (1976) concur to considering N as an individual variable, making *ecthesis* akin to existential instantiation in natural deduction. Whichever view is the correct interpretation, *the essence of*

an ecthetic proof consists in extracting an individual (or a sub-category that can be treated as a whole) with a double predication and then searching for a triple predication before dropping the middle term.

We now illustrate this by giving two examples. First, take the valid syllogism EIO-3: *no M is P; some M is S / some S are not P*. From the second premise extract one or several individuals that are both M and S; because these are M, having property P is precluded by the first premise; that is, there are individuals that are M and S but not P, hence *some S are not P*. Second, take the pair of premises OI-3: *some M are not P; some M are S*. Extract again an individual that is both M and S; but this time the first premise predicates not-P of some individual M without warrant that this coincides with the extracted individual, so that no conclusion follows: this example shows that the invalid syllogisms can also be identified by ecthesis.

THE PROPERTY OF CASE IDENTIFIABILITY

Interestingly, one approach to syllogistic reasoning, namely Stenning and Yule's (1997) which is both logical and psychological, turns out to capture essentially the same notion as ecthesis. They show that syllogisms exist and are soluble owing to one structural property which they call "identification of individual cases". An individual either possesses or does not possess each of the three properties that define the categories S, M, and P; this defines eight types of individuals: S+M+P+, S+M+P-, S+M-P+, S+M-P-, S-M+P+, S-M+P-, S-M-P+, S-M-P-. When the joint premises of a syllogism warrant the existence of such a type, the syllogism is valid. To identify the individual case that defines the conclusion the authors describe two algorithms: one, graphical, which will not concern us, and the other, sentential, which is relevant to our current purpose.

The premises of the syllogisms are first interpreted in propositional terms, which gives the following encoding: all = $X \rightarrow Y$; some = $X \& Y$; no = $X \rightarrow \neg Y$; some not = $X \& \neg Y$. The algorithm has three parts. The first part aims to identify a premise that provides the first two terms of the individual description, called the *source premise*. It is either a unique existential premise, or the unique universal premise that has an end-term subject. (Failure to find either indicates

that there is no valid conclusion). At this stage, one of the terms is necessarily M. The second part aims to complete the description with the second end-term. To do this, the quality (polarity) of M in the incomplete description is compared with the quality of M in the non-source premise (which is always a conditional premise). There are three possibilities: (a) if the qualities match and M is the subject of the non-source premise, a modus ponens is applied and its conclusion (which is the predicate of the non-source premise) provides the third term of the description; (b) if the qualities do not match and M is the predicate of the non-source premise, a modus tollens is applied whose conclusion (the subject of the non-source premise) provides the third term of the description; (c) otherwise there is no conclusion. At this stage, either there is a complete description of an individual case, or there is no conclusion. The third part of the algorithm produces the final conclusion by deleting the middle term and introducing a quantifier (which is existential unless there are two universal premises and only one of them has an end-term subject).

We illustrate the algorithm with two examples. First, consider again EI-3 (*no M is P; some M is S*). It is rewritten as $M \rightarrow \neg P$; $M \& S$. The source premise is the particular premise, which yields $M+S+$ as the first two terms of the description. As $M+$ matches the quality of M in the first premise, modus ponens applies as $M \rightarrow \neg P$; M , to yield $\neg P$ and then the full description $M+S+P-$, hence the conclusion *some S are not P*. Second, consider AO-2 (*all P are M; some S are not M*). The source premise is the particular premise, which yields $S+ M-$ to start the description. Because in the first premise M is predicate and positive, there is a mismatch and modus tollens applies as $P \rightarrow M$; $\neg M$, to yield $\neg P$ and the full description $S+ M- P-$, hence the conclusion *some S are not P*. In both examples, through this procedure an individual has received a double predication twice, viz. $M+S+$ and then $M+P-$ in the first case, $S+ M-$ and then $M-P-$ in the second case to produce the full description (a triple predication), hence the conclusion after abstraction of M. In brief, Stenning and Yule's verbal algorithm turns out to be a general procedure of application of ecthesis to all syllogisms.

Before turning to natural syllogisms, we will have a quick look at the laboratory task.

EVIDENCE OF THE ECTHETIC STRATEGY IN THE FORMAL TASK

If, as will be claimed below, ecthesis is the mechanism that reasoners use to solve natural syllogisms, one can expect to find some trace of it in the formal task; that is, participants of higher cognitive abilities who have reached some critical level in their metacognitive development could apply ecthesis spontaneously. Indeed, the use of ecthesis can be inferred from studies where care was taken to exploit verbal protocols (for more details see Politzer, 2004).

In the first experimental investigation of syllogistic reasoning (and possibly also the very first experimental study of reasoning) Störring (1908) described two strategies, one visual corresponding to the use of diagrams, the other verbal which he called the process of *insertion*. This consists of selecting the end term of one premise and inserting it next to the middle term in the other premise. Then the conclusion is obtained by extraction from the composite expression. For example, given the IA-4 pair of premises, *some P are M; all M are S*, a participant said "all the M, including some P, are S" which by abstraction of M yields *some P are S*. Similarly Ford (1995) described a "substitution behaviour" which consists of replacing one term in a premise with another, as when solving an algebraic problem (which collapses Störring's insertion and abstraction). Keeping the IA-4 pair as an example, the second premise allows one to give the value of S to M and the value of S can be substituted for M in the first premise, hence the conclusion. According to Ford (1995), the premise that provides the replacement term plays the role of a rule relating membership of class M and property S (more generally, of class C and property X), while the premise that contains the term to be replaced provides specific objects whose status with regard to S (generally to C or X) is known. It is noteworthy that specific objects are considered. **The** produce a valid conclusion the process of substitution is guided by two pairs of rules that are formally equivalent to modus ponens for one pair and modus tollens for the other.

In sum, these reports concur to emphasise the pivotal role played by the extraction of a sub-category or an individual from one premise and keeping its two-term characterisation before inserting it in the other premise, in other words they describe the ecthetic strategy in their own way.

Given the evidence of the use of the ecthetic strategy in the laboratory task, one can expect that performance could be enhanced if this strategy could be primed. Indeed this prediction was supported. Politzer and Mercier (2008) used singular syllogisms, that is, syllogisms with one premise in which the classical sentence *some X are Y* is replaced with the definite singular *this X is a Y* or the indefinite singular *there is an X that is a Y*. There was a fourth condition using the definite plural *these X are Y*. As predicted, comparing the *some* condition and the *this* condition (which cumulates singularity and definiteness) performance increased sharply (globally by about 40%) for almost all syllogisms tested. Also, the singular conditions yielded higher performance than their plural counterparts and the same obtained for the definite versus indefinite comparisons. All this means that by referring to definite (rather than indefinite) or to singular (rather than plural) elements of a category, one can prime the exposition strategy among a sizeable proportion of individuals.

Finally, one can find a remarkable insight in Braine's (1998) theoretical approach. Although he did not develop a theory of syllogistic reasoning proper, he hypothesised that what characterises good reasoners is the application of a specific strategy that he called the choice of a "secondary topic". The secondary topic is the subset of the subject category of which the middle term can or cannot be predicated ("the S that are, or are not, M, as determined by the premise relating S and M"). This clearly delivers a doubly predicated subset. Then the conclusion follows by application of a modus ponens or a modus tollens. One of Braine's examples is the AA-3 pair, *all M P; all M S*. Once the secondary topic *the S that are M* has been found, it follows from the first premise, and by application of the generalised modus ponens of his predicate-mental logic (generalising *these S are M; if something is an M, it is a P; therefore these S are P*) that *some S are P*. In brief, one can interpret Braine's

view by saying that good reasoners are those who can execute an ecthetic strategy.

A FIRST STEP TOWARD NATURALISING THE FORMAL TASK: USING KNOWLEDGE-BASED CATEGORISATION

If, in order to prime ecthesis and subsequently solve the syllogism, it is crucial that a double predication should occur, then one can think of taking advantage of one of the most important features of categorisation, namely the possibility for an entity to be referred to by the name of a category (the hyperonym) or by the name of a subcategory (the hyponym). In that case the double characterisation will be realised automatically. Now, consider a quantified sentence F that relates the category *rose* with some other object category (e.g. *fragrant*) whether by quantifying the roses that are or are not fragrant, or quantifying the fragrant objects that are or are not roses. This quantified relationship in which the subcategory *rose* is involved may (or may not) entail another quantified relationship in which the category *flower* is involved. And similarly a quantified sentence G can relate the category *flower* with an object category such as *fragrant* and again there may or may not follow another quantified relationship in which the subcategory *rose* is involved. The entailed relationship is the conclusion of the syllogism whose major premise is one of the quantified sentences F or G, and whose minor premise is the quantified sentence expressing a very small part of the individual's knowledge about the inclusion of categories, namely that all roses are flowers. This analysis provides the rationale for the experiments that will be reported. In an instantiated formal syllogism of the type commonly used in which the minor premise is an A sentence, the relationship expressed is always new information given in a fictitious context (e.g., *all the foreigners are vegetarians* when one is instructed to consider different groups of people) whether or not such a context is explicitly provided. In this sense, the relationship is arbitrary and conventional (as opposed to knowledge-based). It was hypothesised that for the 16 syllogisms with an A minor premise (viz., AA-1 to AA-4, EA-1 to EA-4, IA-1 to IA-4, and OA-1 to OA-4) performance on the formal task would be enhanced if the minor

premise (A) contained a category inclusion relation. This is because the double predication of an individual by both terms of the sentence is automatically satisfied: an entity that is a rose is a flower *eo ipso*. In the first experiment it was hypothesised that merely naming a category (or a subcategory) would be sufficient to cue participants to exploiting the category inclusion and prime the ecthetic process.

Experiment 1

Participants were High School students aged 16 to 18 untutored in logic. They were presented with booklets containing one problem with a different context on each page. For this and the next two experiments, there were 16 different contexts. Each context was introduced by just a few words. There was a control group that received a standard laboratory task and an experimental group that received a modified task in which no minor premise proper appeared but instead a single word appeared (a hyperonym or a hyponym). Each pair of premises (or major premise and single word) was introduced by a few words to set up the context. Participants had to decide whether or not a conclusion necessarily followed, and in the affirmative to choose the quantifier and fill in the blanks (in the SP or the PS order) using the categories underlined. Here is an example for the AA-3 syllogism:

- control condition:

*At an international conference,
all the japanese are jurists
all the japanese are organisers*

- experimental condition (one word replaced the minor premise):

*At an international conference,
all the japanese are jurists
Asians*

In both conditions this was followed by the following multiple choice:

Conclusion:

- all the.....are.....*
- some.....are.....*

- some.....are not.....*
- no.....is.....*
- there is no conclusion that is necessarily true*

The correct answer for the control condition is *some organisers are jurists*, or *some jurists are organisers*, and for the experimental condition *some jurists are Asians* or *some Asians are jurists*; the latter is based on the implicit minor premise *all japanese are Asians* cued by the hyperonym *Asians*.

Results and discussion. Collapsing across the 16 problems, the mean rates of correct response were 49.4% for the control condition and 63.2% for the experimental condition. This overall difference can be regarded as modest in terms of effect size, but there are three problems that gave rise to a ceiling effect with a success rate above 90% in the control condition; when these are removed, the rates of correct response were 39.2% and 56.8%, respectively. This difference was not due to a few problems, but concerns the great majority of the problems: there was a significant increase for eight problems, a non significant increase for three problems, no difference for one problem and a non significant decrease for one problem. This difference was significant ($p < .01$, sign test) and we can conclude that the improvement in performance is robust.

In brief, the mere mention of the S term (which in the present example is a hyperonym, *Asian*) invites the category inclusion of M (japanese) in S and the subsequent processing of individuals that are M and S (viewing a japanese as an Asian). This generalises to the eight problems in the third and fourth figure. The same obtains when the S term mentioned is a hyponym: this invites the category inclusion of S in M and the subsequent processing of individuals that are S and M, which corresponds to the eight problems in the first and second figures.

It might be objected that the cueing word does not necessarily operate by suggesting a category inclusion. For example, in the present example participants could formulate the missing minor premise as *some Asians are japanese*, hence an easy syllogism (All-4) that delivers the appropriate conclusion. However, a problem by problem examination shows that this is exceptional and that, if anything, such a formulation renders the problems more

difficult overall. Nevertheless, the next experiment aimed to test that an inclusion relation between non arbitrary categories explicitly expressed by the *all* minor premise would also result in an enhanced performance.

Experiment 2

Participants were second and third year psychology students untutored in logic. The procedure and materials were the same as in Experiment 1 except for the addition of a third condition in which the minor premise stated explicitly the inclusion relation so that, keeping the scenario and the same mood already used as an example, the pair of premises was:

At an international conference,

all the japanese are jurists

all the japanese are Asians

The results confirmed the observations of the first experiment. Leaving out two syllogisms with a ceiling effect, the percentage of correct responses was 38.2% for the control condition, 54.0% and 51.0% for the cued and the explicit inclusion conditions, respectively. The improvement was significant in both experimental conditions (sign test, $p < .05$). Moreover, the effect of the manipulation was extremely close in the two experimental conditions: the trend in the change in performance (no increase, non significant increase or significant increase) was identical on all problems but one and the same obtains for the rate of correct responses that did not differ significantly except for one problem. We can conclude that the existence of an inclusion relation between categories that is stored in long term memory enhances performance, whether this relation is explicitly or implicitly present in the minor premise (when it is present, the task remains formally equivalent to a standard instantiated syllogism).

Even though the manipulation was successful in two experiments run with different populations, one might imagine alternative explanations for the gain in performance. A very simple explanation could be based on the most conspicuous feature of the categories in the minor premise, namely their high familiarity. Indeed, we have claimed that this is what primes the aesthetic

process when there is an inclusion relation between categories. But it might be argued that familiarity is sufficient, possibly because familiar categories are less demanding for working memory than are the arbitrary categories commonly used. The third experiment aimed to rebutt this objection. If familiarity alone is enough to facilitate the solution, then one should expect people to experience a similar facilitation with other syllogisms, especially with the eight valid syllogisms that have an E minor premise. In addition, the response format was changed to a three-option format in order to ascertain that the previous results were not linked to the five-option format.

Experiment 3

Participants were post-graduate students, mostly from Arts and the Social Sciences, and they were untutored in logic. Like in the second experiment there were three conditions (control, cued, and explicit) but the 16 pairs already studied were supplemented with eight other pairs (AE-1 to AE-4 and IE-1 to IE-4). In addition, the response format was changed as shown in the following examples (still referring to the AA-3 problem):

- for the control condition:

- there is a conclusion that is necessarily true*
jurist(s).....organiser(s)
organiser(s).....jurist(s)

- there is no conclusion that is necessarily true*

- for the two experimental conditions:

- there is a conclusion that is necessarily true*
jurist(s).....Asian(s)
Asian(s).....jurist(s)

- there is no conclusion that is necessarily true*

Results. Two important points deserve consideration. First, for the syllogisms with an A minor premise, the gain in performance was even stronger than it was in the two previous experiments. The same analysis (that excluded three problems with a ceiling effect) indicated an increase in performance on all problems for the cued condition ($p < .001$) and on all but one ($p < .01$) for the

explicit inclusion condition. The rate of correct responses was 34.2% for the control condition and jumped to 48.8% and 54.2% for the cued and the explicit inclusion conditions, respectively. Second, for the eight problems with an E minor premise, as predicted no improvement was observed; discarding again two problems (AE-2 and AE-4) that have a rate of success above 85% in the control condition, there was in fact a decrease in performance ($p < .05$ for both conditions).

Discussion. In this experiment the manipulation which consists in priming ecthesis resulted in increasing the rate of correct responses by about one half. This greater facilitation can be attributed to the population or to the different response format or both. However, the fact that across the three experiments the average rate of success in the experimental conditions does not exceed 60% suggests that the maximal facilitation has not been attained.

The other result may be more important, for it concerns the essence of the ecthetic process. It is based on the notion that whereas an inclusion premise can prime ecthesis, an exclusion premise cannot, and we can now examine more precisely why. To do so, we will contrast the AA-3 and AE-3 pairs of premises using the following instantiation concerning, say, a grocer's goods:

AA-3:

major premise: *all the apples are red*

minor premise: *all apples are fruit*

AE-3:

major premise: *all the apples are red*

minor premise: *no apple is a pear*

Conceiving of an apple as a fruit is automatic and virtually irrepressible due to our knowledge of categories, so that the conclusion of AA-3 *some fruit are red* is compelling. In contrast, conceiving of an apple as a non-pear, however obvious and trivial this may be, is deeply arbitrary, even more so than conceiving of an apple as an object of which some property is predicated, precisely because the number of such properties is relatively limited whereas the categories or properties which contrast with *apple* are potentially infinite.

Whereas one is automatically cued to think of an individual known to be a member of a category X (e.g. an apple) as an instance of its supercategory (fruit), there is no reason for being automatically cued to think of such an individual as a non-X (except for reasons specific to the context, or in the particular case where X and non-X are dichotomous or complementary in the context). In brief, whereas the inclusion premise primes ecthesis by suggesting a double predication for an individual such as being an apple and a fruit, the exclusion premise does not have this power. This explains the predicted failure in using common categories to improve performance with the AE and IE pairs of premises.

So far evidence has been presented which supports the claim that to prime ecthesis it is crucial that there exist a minor premise (explicit or implicit) containing a category inclusion relation retrieved from long term memory. It was mentioned in the first section of this chapter that, in addition, natural syllogisms are typically inserted in a dialogue and that the order of the sentences that constitute the argument, including the conclusion, may differ from the textbook/laboratory presentation. We now adduce experimental evidence that when these requirements are satisfied –that is, when one is dealing with natural syllogisms-- performance is close to the maximum.

NATURAL SYLLOGISMS: IN DIALOGIC SITUATIONS SHARED

BACKGROUND KNOWLEDGE OF CATEGORIES PREWIRES ECTHESIS

Participants in the fourth experiment were readers in a public library who either were University students or already held a degree. The problems were again framed in various scenarios and presented in booklets. There were two experimental conditions defined by the materials. One control condition aimed to present a typical laboratory task. Here is an example, using again the AA-3 pair of premises:

In a park,

all the roses are frozen

all the roses are new species

There were five options to conclude: four options with an A, I, O, or E sentence (*all the new species are frozen, etc.*) and a fifth option *one cannot logically conclude*, the meaning of which was carefully explained in the instructions.

In the experimental condition the context was introduced by a three-sentence scenario that presented two characters. The first character asked a question starting with "is it true that" followed by a sentence that was the conclusion of the syllogism. Then the second character uttered an answer starting with "I have seen that" followed by a sentence that was the major premise of the syllogism. No minor premise was stated: this was assumed to be background knowledge shared by the two interlocutors (and of course shared by the participants) so that, pragmatically, the minor premise can be given the status of an implicated premise. With the AA-3 example, one scenario introduces Mary and Peter who has just been in the park alone. Then the dialogue takes place as follows:

Mary asks: "Is it true that in the park some flowers are frozen?"

Peter replies: "I have seen that in the park all the roses are frozen"

Mary can conclude that the answer to her question is:

it is true *it is false* *it is possible*

The valid syllogisms appeared twice, once with a correct *true* answer, and once with a correct *false* answer. With the current example, the answer is *true*. In the *false* version Mary's question is "*Is it true that in the park no flower is frozen?*" For the invalid syllogisms, the question coincided with the erroneous conclusion that is the most frequent according to the reasoning literature on syllogisms. In all the cases, after answering the three-choice question, participants were asked to justify their choice in their own words.

Results. We apply the same analysis as earlier. The mean percentage of correct answers on the standard task was 47.4 % after discarding four problems (AA-1, AA-4, EA-1, EA-4) for which performance was at a ceiling level (above 85%; the rate was 59.9% when these are included). These values are typical of what is reported for the laboratory task in the literature. In contrast, on the natural syllogism task, the rate of correct responses for the twelve problems without ceiling effect jumped to 78.9%. The improvement was general: there

was no change for one problem and an increase for eleven problems ($p < .001$). Notice that this time the size of the gain is considerable as the rate of success passed from less than 50% to close to 80%.

The analysis of the justifications given in the implicit condition is very informative. For the valid syllogisms, about one half consisted of a demonstration that could be of two kinds: either the implicit premise was stated explicitly, or the whole formal syllogism was stated in full (including the implicit premise now spontaneously made explicit by the participant). This provides compelling evidence that these participants did solve the natural syllogisms with comprehension of their logical structure. Slightly less than one half of the justifications were fully consistent with the answer but not informative enough to constitute a full demonstration. The remaining justifications were either inconsistent with the answer or based on empirical considerations (a few percent in each case).

For the invalid syllogisms the justifications that were compatible with the answer but underinformative constituted one quarter of the cases (and there were also a few percent of incorrect justifications). More important, the justifications that constituted a demonstration that the conclusion was possible but not necessary amounted to 70% of the total. It is also remarkable that it is for these pairs that the greatest amelioration took place: the rate of correct answers shifted from 21%, that is no better than chance, to 85%, that is close to perfect performance. Of course, one must be cautious in interpreting participants' performance. In judging that a conclusion offered to them does not necessarily follow from the premises they are not, strictly speaking, proving that the syllogism is invalid. But they could do so by using the same type of proof applied to each of the quantified sentences (A, I, O, E) and show that none of these necessarily follows. Because the proof is similar in all these cases, there is reason to assume that participants would produce a similar proof, should they be required to do so. This is because the putative conclusion that was offered to them was the most frequent error, so that in all likelihood they could also resist other putative conclusions that are not so enticing. Considering that the subset of invalid syllogisms that have an A premise are notoriously difficult, it is worth

examining why participants' performance was improved in all the experiments reported and more specifically in the last one.

For this purpose we take an IA-1 pair of premises followed by its modal erroneous conclusion which is a *some* sentence (marked below with an asterisk). We compare in turn a standard laboratory problem, its counterpart with a minor premise that has an explicit category inclusion (of the type used in Experiments 2 and 3) and then its dialogic presentation as used in Experiment 4.

Consider first the following artificial syllogism:

some flowers (M) are frozen (P)

all the new species (S) are flowers (M)

To appreciate that it is invalid, one must understand that an individual characterised after the minor premise by S and M (flowers that are new species) need not be characterised by P (frozen) because this individual comes from a subset of M that may or may not coincide with the M-individuals referred to in the major premise. Few reasoners are aware of this. In contrast, given:

some flowers (M) are frozen (P)

all roses (S) are flowers (M)

or even better as in Expt 4:

Mary asks: "Is it true that in the park some roses are frozen?"

Peter replies: "I have seen that in the park some flowers are frozen"

it is apparent from the categorisation stored in long term memory that a rose (S M) is a *particular* flower (a member of a subcategory) and as such need not coincide with any of the members of the flower category that are frozen (M P), which need not be roses: the non-necessary existence of an individual case is readily made available. In other words, knowledge of the categorisation which obliges one to conceive of a rose as a flower also obliges one to conceive of a flower as possibly a rose or not a rose. This justification was expressed in various formulations that can be paraphrased by "there are flowers other than roses so that there may not be frozen roses". Of course, there is some artificiality in the task used in Experiments 2 and 3 due to the minor premise which is pragmatically anomalous (even though the instructions warned that

one of the premises would state "an obvious truth"), so that performance was still far from perfect. But when presented as in Experiment 4, participants not only process a natural dialogue but, more important, focus on a specific statement (the conclusion) to evaluate, as they would in their daily life: then they can exhibit their full grasp of the syllogism.

CONCLUSION

For more than two millennia, since their description by Aristotle until the nineteenth century, logicians and philosophers used to consider syllogisms as the yardstick of rationality and human reasoning abilities. Then, after this view had been abandoned in the wake of the Fregean revolution, surprisingly enough psychologists took a strong interest in a task based on them, which they called *sylogistic reasoning*: it consists of solving instantiated exemplars of formal syllogisms, which amounts to investigating the extent to which people untutored in logic access the formalisation made by classical logicians of a special set of deductive arguments. A century of research on this paradigm has yielded little more than the observation that people resort to various strategies and various heuristics to solve problems that, with a number of notable exceptions, are too hard for the majority of reasoners.

In this chapter a subtly, but radically different view on syllogisms is taken. They are regarded as formal descriptions of the underlying structure of enthymematic arguments that people spontaneously use in their daily argumentation. Their essential characteristic is that the implicit premise contains an inclusion relation between two categories that belong to a hierarchy stored in long term memory. It has been argued that reasoners' competence in using these arguments is based on a mechanism that exploits a fundamental property of formal syllogisms described by Stenning and Yule (1997) as *case identifiability* and that this mechanism, which was outlined by Aristotle as a method of proof called *ecthesis*, turns out to be built-in and executed by the category inclusion structure: this is why, contrary to the formal laboratory task, lay people are surprisingly highly proficient in their spontaneous natural syllogistic reasoning.

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Appendix

The four classical quantified sentences:

- A: *all X are Y* = universal affirmative
E: *no X is Y* = universal negative
I: *some X are Y* = particular affirmative
O: *some X are not Y* = particular negative

The four figures (in the traditional logical numbering):

| | 1 | 2 | 3 | 4 |
|---------------|-----|-----|-----|-----|
| major premise | M P | P M | M P | P M |
| minor premise | S M | S M | M S | M S |

M is the middle term, P and S the end-terms.

The designation of syllogisms:

In a designation such as, e.g., EIO -1 the first three letters indicate the mood, that is, the first premise (the major premise) is an E sentence, the second premise (the minor premise) an I sentence and the conclusion an O sentence; the number indicates the figure.

A example of a formal syllogism (in the AAI-3 mood):

- all M are P*
all M are S
 \therefore *some S are P*

This formal syllogism instantiated:

- all the roses are frozen*
all the roses are new species
 \therefore *some new species are frozen*

The associated natural syllogism:

- all the roses are frozen*
{*all roses are flowers*}
 \therefore *some flowers are frozen*