

A subliminal premise can automatically trigger an elementary deductive inference

Carlo Reverberi (carlo.reverberi@bccn-berlin.de)

Bernstein Centre for Computational Neuroscience, House 6, Philippstr. 13,
10115 Berlin, Germany and
Department of Psychology, Piazza dell'Ateneo Nuovo, 1
20126, Milano, Italy

Michele Burigo (michele.burigo@bp.lnf.it)

Cognitive Neuropsychology Unit, IRCSS "E.Medea", via Don Luigi Monza, 20
23842, Bosisio Parini (LC), Italy

Paolo Cherubini (paolo.cherubini@unimib.it)

Department of Psychology, Piazza dell'Ateneo Nuovo, 1
20126, Milano, Italy

Abstract

We investigated whether a basic deductive inference, namely the modus ponens, is an automatic processing step carried out even in the absence of willingness to reason and awareness of all the premises. We used an exhaustive set of conditional problems concerning numbers, with a subliminal second premise, followed by a target number. Participants evaluated whether the target number was odd or even. The target number could match or not match a valid conclusion endorsed by the premises. We found that evaluations of target numbers matching the conclusion of a modus ponens were faster than the evaluations of numbers following all other types of problems. This finding shows that modus ponens is automatic and can be triggered by subliminal stimuli.

Keywords: deduction; reasoning; subliminal processing.

Introduction

Deductive reasoning has a special status among cognitive processes, because the ability to recognize simple deductive arguments is a core property of rational thought (Rips, 1988). The most intuitively straightforward deductive inference is the one that logicians call Modus Ponens (MP). According to this inference, from the statement "IF so-and-so is true, THEN such-and-such is true" (first premise, or major premise, or P1), and the statement "so-and-so is true" (second premise, or minor premise, or P2), we are entitled to conclude that "such-and-such is true". Rips (1988) argued that Modus Ponens is so central to our notion of intelligence and rationality, that a contrary inference is out of the question: we can conceive the existence of creatures with perceptual systems differing from our own, and even with inferential systems with some differences from our own, but we can hardly conceive the existence of a creature that systematically endorses an inference opposite to MP, concluding "such-and-such is NOT true" from the premises P1 and P2 above (Rips, 1988; Quine, 1970, chap. 6). In reasoning studies, MP inferences are almost error-free, with correctness scores ranging from 90% to 100% (Evans, Newstead, & Byrne, 1993; but the inference is less available if the participants do not trust the premises, see Stevenson &

Over, 1995). Is this important inference an automatic information processing step, or does it involve willingness and attention? Some scholars hold the former view, claiming that MP inferences are triggered whenever the premises match the corresponding logical schema, even without willingness to do so (e.g., Braine & O'Brien, 1998). So far, this issue has not been definitively settled by empirical studies. Nevertheless, some methodologically interesting strategies have been proposed, which capitalize on "priming effects". These are the effects of pre-activated information on the processing of target stimuli (Meyer & Schvaneveldt, 1971; Milliken, Joordens, Merikle, & Seiffert, 1998; Neely, 1977; Tipper, 1985). Thus in the present case, if MP were fully automatic, given the premise pair: (P1) "If there is a 3 then there is an 8" and (P2) "there is a 3", individuals should activate the conclusion "there is an 8", even if they are not willing or interested to do so. Accordingly, if those individuals were later required to perform a simple non-deductive task, e.g. establishing whether a target number is odd or even, their responses should be primed if the target numbers are preceded by premise pairs such as P1 and P2 and the target number coincides with the MP conclusion (e.g., "8"). All previous studies that checked for priming effects driven by MP conclusions used text comprehension tasks, where all the premises of the MP inference were explicitly attended to by participants, who had the goal of understanding a given text passage (Lea, 1995; Rader & Sloutsky, 2002). Under those circumstances it is difficult to demonstrate that participants were not voluntarily reasoning, even though they were not told to do so. In the present study we eliminated that confound by investigating whether MP inferences are activated when participants are not aware of one of the triggering premises, which is presented subliminally (Naccache & Dehaene, 2001b). The finding that valid conclusions of MP problems prime subsequent targets when one of the problem premises is not consciously available to the participant would indicate *both* that the MP inference could be triggered by subliminal stimuli and that it could be carried out without voluntary control.

Experiment

Methods

Participants. Fifty-four (44 females, 10 males) graduate and undergraduate students from the University of Milano-Bicocca participated in the experiment in exchange for course credits.

Stimuli. Overall the experiment involved the presentation of 328 trials. 264 were number evaluation trials and 64 were sentence recognition trials. Each number evaluation trial was composed of two premises and a target number. The first premises (P1) were conditional statements concerning numbers (e.g., “if there is a 2 then there is a 4”). The second premises (P2) and the targets (T) were numbers (e.g., “2”). The structure of the sentence recognition trials was identical to the number evaluation trials, with the exception of the targets. In those trials, the targets were composed of two conditional statements. One of the two statements was identical to P1.

In the following paragraphs, problems will be indicated by stating their four arguments (literals and negations). For instance, “p not q r p” (abbreviated to “p.nq.r.p”) stands for “if there is a p then there is not a q” (P1), “r” (P2), “p” (T). Letters stand for Arabic numerals from 1 to 9.

The first premises (P1) used in the experiment were generated by orthogonally rotating the presence/absence of negations on the two literals. This provided four different structures: if p then q, if not p then q, if p then not q, if not p then not q. The second premises (P2) were either identical (match trials) or different (mismatch trials) to one of the numbers (p, q) involved in P1. In particular, in match trials, each P1 type was followed half of the time by “p” and half of the time by “q”. Thus P2 matched either the first or second literal of P1. In the mismatch trials each P1 type was followed by an “r”, i.e. a number that was not mentioned in P1. Overall the manipulations on P1 and P2 generated 12 pairs of premises. The target was different depending on whether the trial consisted in number evaluation or sentence recognition. In the sentence recognition trials, the target was composed of two conditional sentences. One of the two sentences was identical to the P1 used in the same trial. In the number evaluation trials, each one of the 12 pairs of premises was coupled half of the time with a “p” target number, and the other half with a “q” target number, accounting for 24 types of trials. Furthermore, in the case of mismatch conditions, the target number could also be an “r” or an “s”: i.e., a number identical to P2 (“r”) or a number not presented in the two premises (“s”). Thus overall, 32 different types of number evaluation trials were devised. The whole array of valid and invalid inferences typically studied with conditional premises is a subset of our problems. For example, in our set there were instances of the valid modus tollens schema (MT: if A then B; not B; therefore not A, translating into “np.nq.q.p”, or “np.q.r.p”). Furthermore, there were some classic fallacious inferences that are often accepted by naïve reasoners (“affirmation of the consequent” and “denial of the antecedent”). This

variety of problems allowed for planned comparisons of the effects of different valid and invalid schemata in the analyses. It was also possible to control for parasite effects caused by matches between the target number and the second premise, independently from the conclusion endorsed by the premises.

Procedure. Participants were presented with the stimuli described in the preceding section. Each trial started with a fixation point (1000 ms), followed by P1 for 2500 ms. Participants were told that they had to read and remember P1. After P1, P2 was briefly presented (50 ms), masked by two strings of 10 random characters presented for 83 ms before and after P2 (Fig. 1; in the figure only 6 characters are reported). This procedure prevented subjects from being aware of the presentation of P2. After P2 there was a delay of 750 ms in the long Inter stimulus Interval (ISI) group, and no delay for the short ISI group. This manipulation was introduced in order to sample priming effects in a wider time window after presentation of P2 (Draine & Greenwald, 1998). Finally, the target was presented. In the case of sentence recognition trials, a pair of sentences was presented for max 4000 ms. By contrast, in the number evaluation trials, a number was presented for max 200 ms. The target disappeared as soon as the participants pressed the response button. If no answer was given within the allowed time, the trial ended and was scored as incorrect. The task participants had to perform depended on whether a sentence

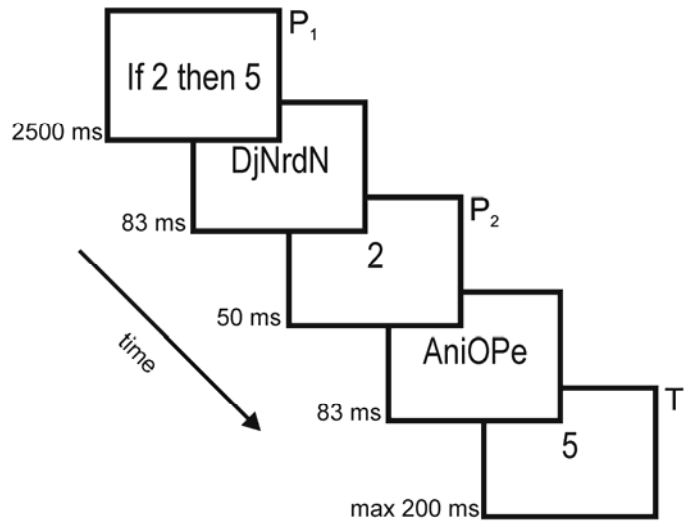


Figure 1. An example trial

recognition trial or a number evaluation trial was being presented. In the sentence recognition trials, participants had to identify which out of the two sentences was identical to P1. In number evaluation trials, the participants were required to judge whether the number was odd or even. After the experiment the participants were asked to indicate what they saw after the first sentence. None of them reported having seen a number (the masked P2), while all of

them reported seeing a flickering string of random letters. Before the experimental session, all participants underwent a 40-trial training session with correctness feedback. Response Times (RTs) on the number evaluation tasks were the main dependent variable for assessing whether processing of targets was affected by the deductive conclusions enabled by the two premises. Subjects with an average score lower than 90% on the sentence recognition trials were discarded from further analyses. This was necessary in order to be sure that participant adequately represented P1 in working memory.

Apparatus. The experiment was programmed and administered using Presentation™. The CRT screen was set at resolution 1024 x 768 pixels and at 60 Hz refreshing rate. Two buttons of a serial mouse were used as response keys. Participants responded with the index fingers of both hands.

Results

Thirteen participants were discarded from analyses because they did not reach 90% accuracy levels in the sentence recognition trials. All remaining 41 participants had accuracies > 90% in both sentence recognition and number evaluation trials. In line with preceding studies on priming (Naccache & Dehaene, 2001a, 2001b), on the number evaluation trials we considered only responses with RTs between 250 ms and 1000 ms (92.5% of all responses). We planned to compare the RTs of the modus ponens (MP) problems (“p.q.p.q.”) with the RTs of: (i) all other problems that endorsed a valid or fallacious conclusion identical to the target number (e.g.: MP vs. modus tollens; MP vs. affirmation of the consequent; MP vs. denial of the antecedent), and (ii) all problems that did not support a conclusion identical to the target number, but differed in one feature only from the MP problems (e.g.: MP vs. “p.q.r.q.”; MP vs. “p.nq.p.q.”, etc.). Overall, 9 problems were involved in the planned comparisons. First, we assessed the effect of ISI length on the reaction times of these problems. A 9 x 2 ANOVA factoring the problem type as a within-participant factor and the ISI as a between-participant factor yielded reliable main effects of both problem type [$F(8,312) = 2.17$, $p < .05$], and ISI length [short-ISI: mean RTs = 646 ms; long-ISI: mean RTs = 584 ms; $F(1,39) = 4.27$, $p < .05$]. However, given that the interaction was not significant [$F(8,312) = .83$], we pooled all participants together in the subsequent analyses. Second, we compared the RTs of the Modus Ponens with the RTs of the critical problem p.q.r.q, i.e. the problem that is identical to MP apart from the presence of a subliminal non-matching minor premise “r”. MP was significantly faster ($t(40)=2.78$, $p = .0082$, two-tailed). Finally, we further checked whether MP was also faster than the other 8 relevant problems. To that aim, a conjunction analysis was run. For the conjunction analysis an α -level of .05 (one-tailed) was used: this corresponds to requiring a $p < .05$ for each pair-wise comparison considered in the conjunctin. This procedure is valid, even though it has been noticed that it might be even too

conservative (Nichols, Brett, Andersson, Wager, & Poline, 2005). Each of the further 8 planned comparisons are reported in Tab. 1. We found that in MP trials the target was processed faster than in all the other trial types ($t(40)=1.89$, $p = .033$). In particular (Tab. 1), MP trials (p.q.p.q) were faster than trials with exactly the same P1 and P2 but a target number that differed from the MP conclusion (p.q.p.p). Furthermore, the MP trials were also faster than MT trials endorsing a valid conclusion matching the target number (p.nq.q.p), and they were faster than fallacies such as the affirmation of the consequent (p.q.q.p) or the negation of the antecedent (np.nq.p.q). Overall, this indicates that a priming effect was selectively present in the trials where the target was the conclusion of a MP inference.

No priming effects were found when a separate analysis was carried out of the 13 participants who had been discarded for low-level performance on the sentence recognition tasks.

Discussion

In the present study we investigated whether the modus ponens inference, a basic inference that is at the core of human rational thought (Rips, 1988, 1994), is an automatic information processing step that can be carried out even without the willingness to do so. Furthermore, we investigated whether MP requires a fully explicit representation of its premises, or can also be triggered by stimuli that are not consciously perceived. We devised an experiment in which the minor premise of a series of deductive problems was presented subliminally (Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Naccache & Dehaene, 2001b).

Table 1. Pairwise comparisons of the RT to the MP problems with the RTs to the other 9 relevant problems.

Problems	RT(ms)	Comparison with p.q.p.q:		
		$t(40)$	p	η_p^2
p.q.p.q	601			
p.q.r.q	622	2.78	.0082	.162
p.q.p.p	621	2.51	.0082	.136
np.q.r.q	629	2.73	.0047	.157
p.nq.p.q	619	1.96	.0286	.088
np.q.p.q	617	1.89	.0333	.082
np.nq.q.p	635	5.21	<.0001	.404
np.q.r.p	625	2.46	.0090	.132
p.q.q.p	622	2.75	.0044	.159
np.nq.p.q	630	3.73	.0003	.258

Subjects were required to perform a non-reasoning task on subsequent conclusions. Strikingly, we found that - given an explicit premise “if p then q” - a subsequent subliminal premise “p” produced a positive priming effect on a target number corresponding to the MP conclusion (“q”), compared to a problem that was fully identical apart from the presence of a subliminal non-matching premise “r”,

instead of “p”. Notice that subjects were not even aware of the presence of a minor premise, let alone of the differences among different minor premises and their integrability to the major premise. Moreover, we evaluated whether the priming effect also occurs when MP is compared with a variety of different problem types, including the modus tollens and the fallacies of the affirmation of the consequent and the negation of the antecedent. The effect was present in all comparisons: processing targets embedded in modus ponens problems was systematically faster. Furthermore, the absence of priming effect with the affirmation of the consequent fallacy (p.q.q.p) shows that the subliminal processing of conditional premises is unidirectional. It can only go from the antecedent to the consequent. This finding supports the idea that the MP is triggered by a specific logical circuit, and is not a side effect of a more general, bidirectional (and thus logically invalid) spreading-activation mechanism between the antecedent and the consequent of a conditional premise. Finally, we showed that the MP priming effect was observable only in those participants who adequately attended and correctly encoded the conditional major premise in working memory. Thus, the implicit, subliminal representation of the minor premise can trigger the modus ponens inference only if the major premise is explicitly and adequately represented in working memory.

These findings strongly argue for the automaticity of the modus ponens, as suggested by the “mental logic” theory of deductive reasoning (Braine & O'Brien, 1998). Furthermore, they suggest that a MP inference can be triggered by subliminal stimuli and carried out without subjects being aware of it. Other valid deductive inferences – such as modus tollens – do not share these characteristics. The automaticity of the MP, and its reliance on a specific, dedicated logical circuit, supports the idea that some very basic, intuitively valid logical schemata might constitute at least part of the core of human reasoning competence.

Our results extend the list of the cognitive activities that can be performed without consciousness. While it is largely accepted that subliminal stimuli can activate lower-level processing (Greenwald, 1992), the possibility that subliminal stimuli can also trigger semantic (Dell'Acqua & Grainger, 1999; Naccache & Dehaene, 2001b) or inferential (e.g. deduction, as in the present study) computations is debated (for a review see Kouider & Dehaene, 2007). However, in recent years, an increasing number of studies is providing evidence of the subliminal activation of high-level processing, including decision making (Dijksterhuis, Bos, Nordgren, & van Baaren, 2006; Soon, Brass, Heinze, & Haynes, 2008), motivation (Pessiglione et al., 2007), emotion (Etkin et al., 2004), and extraction of formal features from audio streams (Pena, Bonatti, Nespor, & Mehler, 2002). This study indicates that a critical component of deductive reasoning – the modus ponens – can be triggered by a non-conscious stimulus and performed without voluntary control.

Conclusions

The present study provides evidence that the modus ponens (“if p then q; p; therefore q”), contrary to any other valid or invalid inference that we tested, is an automatic information processing step that can be performed even where individuals are not aware of a subliminal second premise (“p”), as long as they paid attention to the first premise (“if p then q”) and correctly retained it in working memory. These results extend the variety of known high-level cognitive tasks that can be performed unconsciously, by adding a critical component of deductive reasoning.

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