

# EVIDENCE OF ACCURATE LOGICAL REASONING IN ONLINE SENTENCE COMPREHENSION

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From Wason's (1968) selection task to dual-process theories of cognition (Evans & Stanovich, 2013; Kahneman, 2011), a rich empirical literature within psychology has argued that fast and automatic reasoning is not normatively accurate. On the other hand, linguistic theories that seek to explain reliable patterns of linguistic judgments attribute a high degree of logical sophistication to all linguistic humans. For example, most accounts of scalar implicature (Horn, 1972) and of the distribution of negative polarity items (NPIs; words like "any" and "yet") invoke entailment (e.g. Ladusaw, 1983)--a relation between sentences whereby one is true if another is true. These accounts presuppose that this logical property can be computed effortlessly, accurately, and automatically by speakers without any logical training. However, there is little evidence that speakers do compute such logical relations online during sentence comprehension.

Two novel self-paced reading experiments tested for signatures of accurate, intuitive inferences made during sentence comprehension. Experiment 1 tested whether people detect logical contradictions. Participants (N=400) read 12 target items displayed line-by-line, with line breaks at clausal boundaries. An example item:

- (1) A group of scientists wanted to know whether spotted rats,
- (2) who are pickier eaters than other rats, liked a new kind of food.
- (3) They tested white, black, and spotted rats of both sexes.
- (4) The scientists found that QUANT1 of the rats loved the food.
- (5) Since QUANT2 of the rats loved the food,
- (6) the researchers plan to issue a recommendation based on their findings.

The participants pressed [SPACE] to reveal the next line. Each item contained a 'premise' in line 4 and a "since" clause, introducing a 'conclusion' in line 5. The two lines differed only in the quantifiers they used. There were two conditions where the premise with QUANT1 was identical to the conclusion with QUANT2, two conditions where it differed from but entailed the conclusion, and two conditions where it contradicted it, i.e. six experimental conditions in total:

	QUANT1	QUANT2
IDENTICAL	some	some
IDENTICAL	not all	not all
ENTAILS	all	some
ENTAILS	none	not all
CONTRADICTS	none	some
CONTRADICTS	all	not all

Participants took significantly longer to advance the conclusion line when it contradicted the premise than when it was entailed by the premise (LMER effect of condition:  $\chi^2=230.5$ ,  $p < 0.001$ ), consistent with rapid, normatively accurate sensitivity to the logical relations between these clauses.

Experiment 2 (N=400) modified this paradigm to test whether participants differentiate inferences that are licensed or unlicensed by entailment relations between sentences. Items were modified so that the conclusion clause began with "now that they knew that...", presupposing that the continuation appeared earlier in the discourse. We manipulated the quantifiers (QUANT) in both the premise and the conclusion as well as the noun phrase (NP) in the premise. Thus, lines 4 and 5 differed from those of Experiment 1 in the following way :

- (4) The scientists found that QUANT ((male) spotted) rats loved the food.  
 (5) Now that they knew that QUANT of the spotted rats loved the food,

The same quantifier was used in both the premise and the conclusion. The premise NP appeared with two modifiers (e.g. male spotted rats), one modifier (e.g. spotted rats), or no modifiers (e.g. rats). The conclusion NP always appeared with one modifier. Thus, the premise NP was a subset (male spotted rats  $\subset$  spotted rats), identical to (spotted rats = spotted rats), or a superset (rats  $\supset$  spotted rats) of the conclusion NP. Four quantifiers by three containment relations (identity, subset, superset) yielded 12 experimental conditions . Depending on the combination of the quantifier and containment, there were four conditions where the premise was identical to the conclusion, four conditions where it differed from but entailed the conclusion, and four where it did not entail the conclusion:

	identity	subset	superset
all	IDENTICAL	-ENTAILED	ENTAILED
none	IDENTICAL	-ENTAILED	ENTAILED
not all	IDENTICAL	ENTAILED	-ENTAILED
some	IDENTICAL	ENTAILED	-ENTAILED

A significant interaction of containment by direction of entailment ( $\chi^2=13.8$ ,  $p < 0.001$ ) revealed that participants took longer to advance the conclusion line when it was not entailed by the premise, again consistent with intuitive sensitivity to logical relations between clauses.

We discuss our findings in relation to decades of psychological research on dual-process theories which argues the opposite, as well as to more sympathetic accounts of 'natural logic' in reasoning (e.g. Braine and O'Brien, 1998) and in grammar (e.g. Gajewski, 2002). We argue that logical competence is inherent in language comprehension, which can reveal the human capacity for reasoning more reliably than test-taking or puzzle-solving tasks.