ACCURATE LOGICAL REASONING IN ONLINE SENTENCE COMPREHENSION

From Wason's selection task (Wason, 1968) to dual-process theories of cognition (Evans & Stanovich, 2013; Kahneman, 2011), a rich empirical literature within psychology has argued that human 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 the distribution of negative polarity items (NPIs) invoke *entailment directionality* (e.g. Ladusaw, 1983), presupposing that this logical property can be computed effortlessly, accurately, and automatically by speakers without any logical training. However, outside of acceptability judgements, which have alternative interpretations (c.f. Hoeksema, 2012), there is little evidence that speakers compute entailment directionality or entailment relations between sentences during sentence comprehension (see Agmon et al., 2019).

Two novel self-paced reading experiments tested for signatures of accurate inferences made during sentence comprehension. Experiment 1 (N = 400) tested whether speakers detect logical contradictions. Participants read 12 target items displayed line by line, with line breaks at clausal boundaries. They pressed [SPACE] to advance the next line. Each item contained a "premise" in line 3 and a *since*-clause introducing a "conclusion" in line 4 (see Figure 1). The two lines differed only in the quantifiers they used (*some, all, none, not all*). 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 (Figure 2). Participants took significantly longer to advance the conclusion line when it contradicted the premise than when it was entailed by the premise (Figure 5, 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) used the same paradigm to test whether subtler unlicensed inferences are detected even in the absence of strict contradictions. Items were modified so that the conclusion clause began with *now that they knew that ...*, presupposing that what comes next 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 (Figure 3). The quantifier was kept constant between 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 and three containment relations (*IDENTITY*, *SUBSET*, *SUPERSET*) yielded 4 × 3 = 12 experimental conditions in total. 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 (Figure 4). A significant interaction of containment by direction of entailment (Figure 6, $\chi^2 = 13.8$, $p < 0.001$) revealed that participants took longer to advance the conclusion line when it was not entailed by the premise, again consistent with rapid sensitivity to logical relations between clauses.

Our findings suggest that language processing involves automatic, accurate, and spontaneous logical computations, even in the absence of a question that requires making these inferences to verify text comprehension (Tiemann, 2014). How can we square this conclusion with decades of psychological research arguing for the opposite? One possibility is that natural logical competence is more easily revealed by tasks that requires mere language comprehension, and do not involve test-taking or puzzle-solving.

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

Figure 1: An example item in Experiment 1. The conclusion line is boxed.

	QUANT1	*QUANT2*
CONTR	*none*	*some*
CONTR	*all*	*not all*
ENTAIL	*all*	*some*
ENTAIL	*none*	*not all*
IDENT	*some*	*some*
IDENT	*not all*	*not all*

Figure 2: Exp 1 conditions.

(1) *A group of scientists tested a new type of pet food for rats,*
(2) *They tested white, black, and spotted rats of both sexes.*
(3) *The scientists found that QUANT of the ((male) spotted) rats loved the food.*
(4) *Now that they knew that QUANT of the spotted rats loved the food,*
(5) *they decided to issue a recommendation based on their findings.*

Figure 3: An example item in Experiment 2. The conclusion line is boxed.

	ID	*SUB*	*SUP*
all	ID	¬ENT	ENT
none	ID	¬ENT	ENT
not all	ID	ENT	¬ENT
some	ID	ENT	¬ENT

Figure 4: Exp 2 conditions.

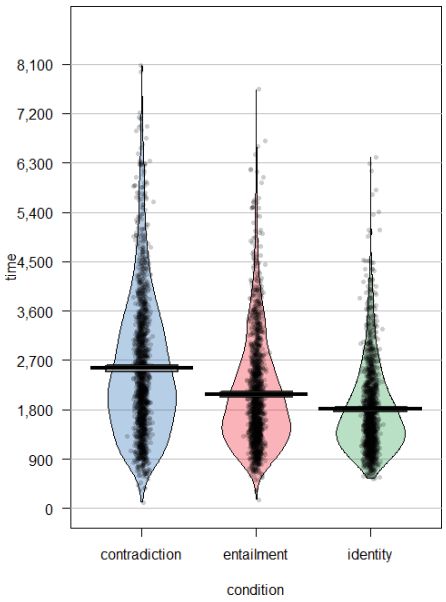

Figure 5: Experiment 1 results.

REFERENCES

Agmon, G., Loewenstein, Y., & Grodzinsky, Y. (2019). Measuring the cognitive cost of downward monotonicity by controlling for negative polarity. *Glossa: A Journal of General Linguistics*, *4*(1).

Evans, J. S. B. T., & Stanovich, K. E. (2013). Dual-process theories of higher cognition: Advancing the debate. *Perspectives on Psychological Science*, *8*(3).

Hoeksema, J. (2012). On the natural history of negative polarity items. *Linguistic Analysis*, *38*(1/2).

Kahneman, D. (2011). *Thinking, Fast and Slow*.

Ladusaw, W. A. (1983). Logical form and conditions on grammaticality. *Linguistics and Philosophy*, *6*(3).

Tiemann, S. (2014). *The processing of* wieder *('again') and other presupposition triggers* (Doctoral dissertation). Eberhard Karls Universität Tübingen.

Wason, P. C. (1968). Reasoning about a rule. *Quarterly Journal of Experimental Psychology*, *20*(3).

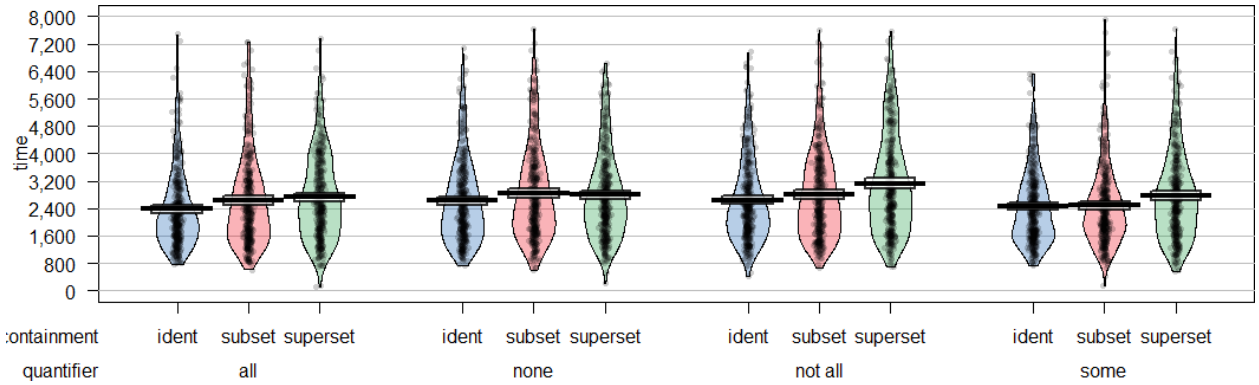

Figure 6: Experiment 2 results. The *y*-axis shows RT for the conclusion line in each condition.