Fail fast or succeed slowly: Good-enough processing can mask interference effects

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On a cue-based retrieval account of sentence processing (Van Dyke & Lewis, 2003; Vasishth & Lewis, 2006), grammatical heads such as verbs provide retrieval cues that are used to distinguish between the target item and competitors in memory. Similarity based interference occurs when items share retrieval cues, which makes it harder to distinguish between them, causing both longer reading times (RTs) and lower question-response accuracy. Since lower accuracy could be the result from either incorrectly retrieving a competitor or simply failing to complete a retrieval (an unstarted or aborted process), it is unclear how RTs are related to question-response accuracy. We investigated this question with two approaches: (i) by using the outcome of multinomial processing trees modeling accuracy in a linear mixed model with RTs as a dependent variable, and (ii) by fitting RTs and accuracy with ACT-R.

Experiment

In a self-paced reading experiment (N=84), we investigated interference effects in subject-verb dependencies in German by manipulating the number feature of two intervening competitor NPs (*the student/s of the teacher/s*). In the high interference (HI) condition, the two competitors share the feature singular (*sg*) with the target (*The driver*), while in the low interference (LI) condition the competitor NPs have, in contrast, the feature plural (*pl*). In order to investigate accuracy, we had yes-no questions targeting either the dependency between the subject and the embedded verb (*had transported*), or the dependency between the subject and the matrix verb (*sat*).

(1) a. HIGH INTERFERENCE

Der **Fahrer**, der den
The.sg.nom driver, who.sg.nom the.sg.acc
Schüler des Lehrers **transportiert**
student the.sg.gen teacher **transported**
hatte, saß angeschnallt im Bus.
had.sg, sat.sg using a belt in the bus.

'The driver, who had transported the student of the teacher, sat using a belt in the bus'

b. LOW INTERFERENCE

Der **Fahrer**, der die
The.sg.nom driver, who.sg.nom the.pl.acc
Schüler der Lehrer **transportiert**
student the.pl.gen teacher **transported**
hatte, saß angeschnallt im Bus.
had.sg, sat.sg using a belt in the bus.

'The driver, who had transported the students of the teachers, sat using a belt in the bus'

We found the expected retrieval interference effect: longer RTs in HI vs. LI at the embedded verb (Posterior Mean= 0.02; 95% Credible Interval $= [0.00, 0.04]$)[1] , as well as lower accuracy across question types in HI vs LI (PM= -0.40; 95% CI= $[-0.65, -0.16]$).

Multinomial Processing Trees

In order to investigate the relationship between latencies and question-response accuracy, we estimated the probability of successfully completing *any* retrieval at the embedded verb (R), the probability of the retrieval of the target conditional on R (C), and the bias to guess "Yes" (G). These estimations were carried out by fitting multinomial processing trees (MPT: Batchelder and Riefer, 1999) using Bayesian hierarchical modeling (Matzke, Dolan, Batchelder, & Wagenmakers, 2013). The model in Figure 1 postulates four processing trees depending on the correct answer and on the targeted verb. We estimated the parameters for the HI and LI conditions, assuming that G was independent of the manipulation. In order to reduce the number of parameters in the MPT, we further assumed no (or negligible) interference at the retrieval triggered by the main verb. If the parser completed a retrieval (even an incorrect one) at the embedded verb, a complete sentence representation will allow to give a correct answer for questions targeting the main verb. Even though it has been shown that already integrated nouns can interfere with subject retrieval of later verbs (Van Dyke, 2007), retrieval at the main verb may be easier here because only a subject-verb dependency has to be completed (in contrast to both subject-

[1] All the statistical analysis were done in the Stan probabilistic programming language. We report Bayesian linear mixed-effects models on $-1000/\text{RTs}$.

and object-verb dependencies for the embedded verb) and because the retrieval is facilitated by the use of cues such as attachment status and clause, which were unavailable for the embedded verb. Furthermore, we found no effect in RTs at the main verb, while the response question accuracy was significantly higher for questions targeting the main verb.

The MPT model revealed that both R and C were higher for LI conditions compared to HI conditions (see table 1). The difference in retrieval probability entails that more often in HI than in LI conditions, readers did not complete the dependency at the verb, and resorted to guessing at the stage of the comprehension question (in line with one possible conception of good-enough parsing; Ferreira, Bailey, & Ferraro, 2002). The model also yielded estimates of subject-level retrieval probabilities, which we regressed against RTs for each condition. The regressions showed that an increase in retrieval probability is associated with an increase in RTs (HI: PM= 0.05; 95% CI= $[0.00, 0.10]$; LI: PM= 0.08; 95% CI= $[0.02, 0.14]$). This suggests that a failed retrieval process is faster than a complete one. Taken together, these findings support the idea that at the locus of interference, the RT of each observation (for each subject) is generated by either fast good-enough parsing associated with a failed retrieval, or relatively slow, thorough parsing associated with retrieval completion. While HI produces latencies in retrieval completion in comparison with LI, it is also more likely that observations belonging to the HI condition will be generated by fast good-enough parsing. This suggests that in other experiments the selective good-enough parsing strategy associated with retrieval failure has the potential to mask interference if individual-level retrieval probability is ignored. Crucially, a linear mixed model including the estimates of retrieval as a covariate supports our hypothesis: We found a stronger effect of interference in our data when the individual-level measure of retrieval completion was included (PM= 0.04; 95% CI= $[0.01, 0.06]$).

Table 1: Parameters of the MPT model.

	Posterior Mean Probability	95% Credible Interval 2.5%	97.5%
R_{HI}	0.61	0.38	0.77
R_{LI}	0.81	0.68	0.90
C_{HI}	0.89	0.68	0.99
C_{LI}	0.95	0.85	1.00
G	0.69	0.54	0.82
R_{LI}-R_{HI}	0.20	0.02	0.42
C_{LI}-C_{HI}	0.06	−0.09	0.27

ACT-R

We implemented the assumption that readers follow a good-enough parsing strategy when a retrieval process fails using ACT-R (Anderson et al., 2004). The model implements the good-enough parsing by including an integration process of 150 ms only if the retrieval is completed. For each participant, we fitted a model to RTs and question-response accuracies by varying the retrieval threshold while keeping all other parameters fixed. The ACT-R model replicates the findings from the MPTs: higher retrieval probability and correct retrievals in LI in comparison with HI (0.78 vs. 0.67; 0.99 vs. 0.97), while it accounts for the observed RTs and accuracies.

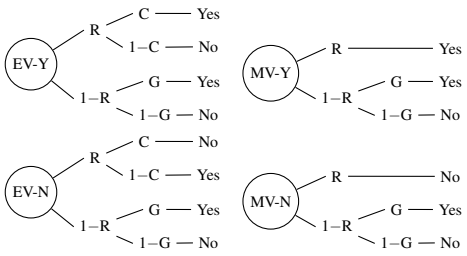

Figure 1: Multinomial processing trees. EV and MV indicate questions targeting the embedded verb and the main verb respectively; Y and N indicate whether the correct answer for the question was "Yes" or "No" respectively.

Conclusion

In sum, the results show that good-enough parsing, as construed above, may mask slowdowns due to interference, if both RTs and accuracy are not taken into account.

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References

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C., & Qin, Y. (2004). An integrated theory of the mind. *Psychological Review*, *111*(4), 1036–1060.

Batchelder, W. H. & Riefer, D. M. (1999). Theoretical and empirical review of multinomial process tree modeling. *Psychonomic Bulletin & Review*, *6*(1), 57–86.

Ferreira, F., Bailey, K. G. D., & Ferraro, V. (2002). Good-enough representations in language comprehension. *Current Directions in Psychological Science*, *11*(1), 11–15.

Matzke, D., Dolan, C. V., Batchelder, W. H., & Wagenmakers, E.-J. (2013). Bayesian estimation of multinomial processing tree models with heterogeneity in participants and items. *Psychometrika*, 1–31.

Van Dyke, J. A. (2007). Interference effects from grammatically unavailable constituents during sentence processing. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, *33*(2), 407.

Van Dyke, J. A. & Lewis, R. L. (2003). Distinguishing effects of structure and decay on attachment and repair: A cue-based parsing account of recovery from misanalyzed ambiguities. *Journal of Memory and Language*, *49*(3), 285–316.

Vasishth, S. & Lewis, R. L. (2006). Argument-head distance and processing complexity: Explaining both locality and antilocality effects. *Language*, *82*(4), 767–794.