Disentangling Semantic Empty-Set Effects in Quantifier Comprehension From Simple Associations: Processing Evidence From Exceptive-Additives

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Introduction

- Bott et al. (2019) proposed an algorithmic theory of quantifier interpretation
- Basic division between quantifiers that have the empty set as witness set ($\emptyset$ Qs) and quantifiers that don't ($\neg\emptyset$ Qs)
- Any $\neg\emptyset$ quantifier can be handled by the following algorithm

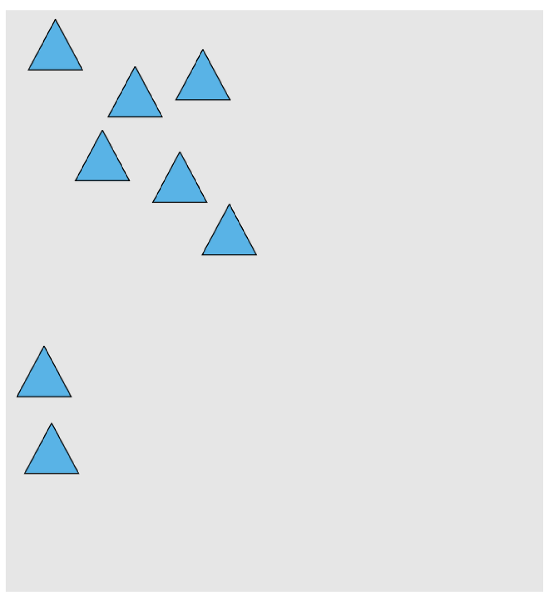
Simple Expansion (encoding presence not absence of properties): $Q(A, B)$ is true iff the Bs in A are a witness set of $Q(A)$

(1) a. At least two ($\neg\emptyset$ Q) girls tickled more than three ($\neg\emptyset$ Q) boys.
    b. At most two ($\emptyset$ Q) girls tickled more than three ($\neg\emptyset$ Q) boys.

- (1-a), but not (1-b), can be verified using the Simple Expansion algorithm
- Sentences with at least one $\emptyset$-Q need a more complex algorithm with an extra rule for empty-set (ES) situations (cf. (2-a))
- Explanation of the unlearnability of non-conservative quantifiers (Hunter and Lidz, 2012), complexity of monotone decreasing quantifiers (Just and Carpenter, 1971, a.o.) and ES effects (Bott et al., 2019)

ES effects and their explanations

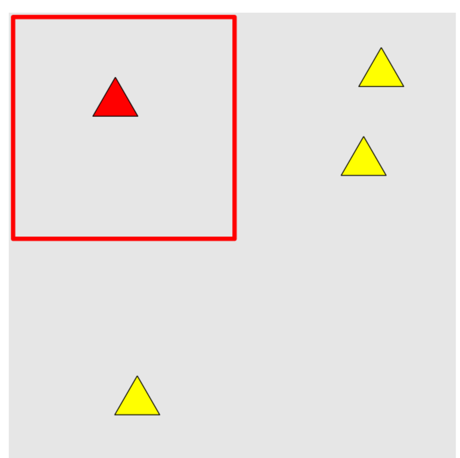
(2) a) At most one ($\emptyset$) triangle is red. b) At least three ($\neg\emptyset$) triangles are blue.



- **ES effect**: Difficulty when evaluating $\emptyset$ Qs in empty-set situations
- Higher **error rates** and substantially increased **judgment RTs**
  - Differential effect: difficulty strongly increased in quantifier iterations (type $\langle 1, 1, 2\rangle$) relative to simply quantified ($\langle 1, 1\rangle$) sentences ($\approx$50 vs. 20% errors)
- Bott et al. (2019) explain this pattern by the specific algorithmic rules
- Effect may also be due to simple mismatch of color features of the adjective and colors in the picture

Testing ES effects in *außer*-sentences

(3) Besides the marked one, at most one ($\emptyset$) further triangle is red.



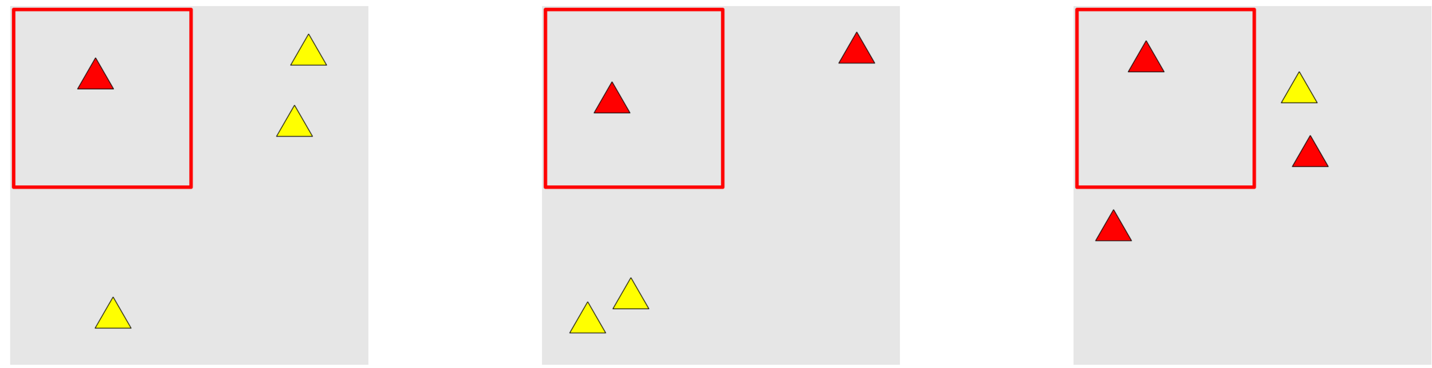
- Additive inference:
  - Marked one is red
  - Not necessarily part of assertion

$\Rightarrow$ ES situation despite presence of mentioned color allows **testing for ES effects without superficial mismatch**

- **Exceptive-additive sentences involve three sets** of entities (domain & scope of Q + objects introduced in *'außer'*-phrase; akin to type $< 1, 1, 1 >$ quantifiers)
- **Control experiment tested for the status of the additive inference**

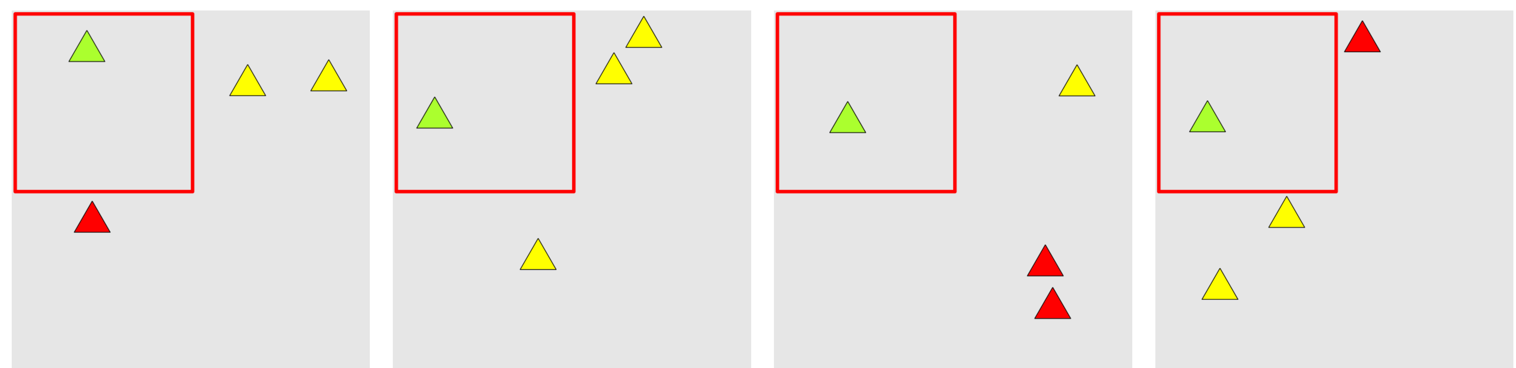
Methods: web-based experiment ($N = 80$)

- Two stages in each trial: Comprehension (self-paced reading) followed by verification stage (truth-evaluation wrt picture)
- Accuracy and judgment RTs reflect verification complexity



(a) 0-model (b) 1-model (c) 2-model

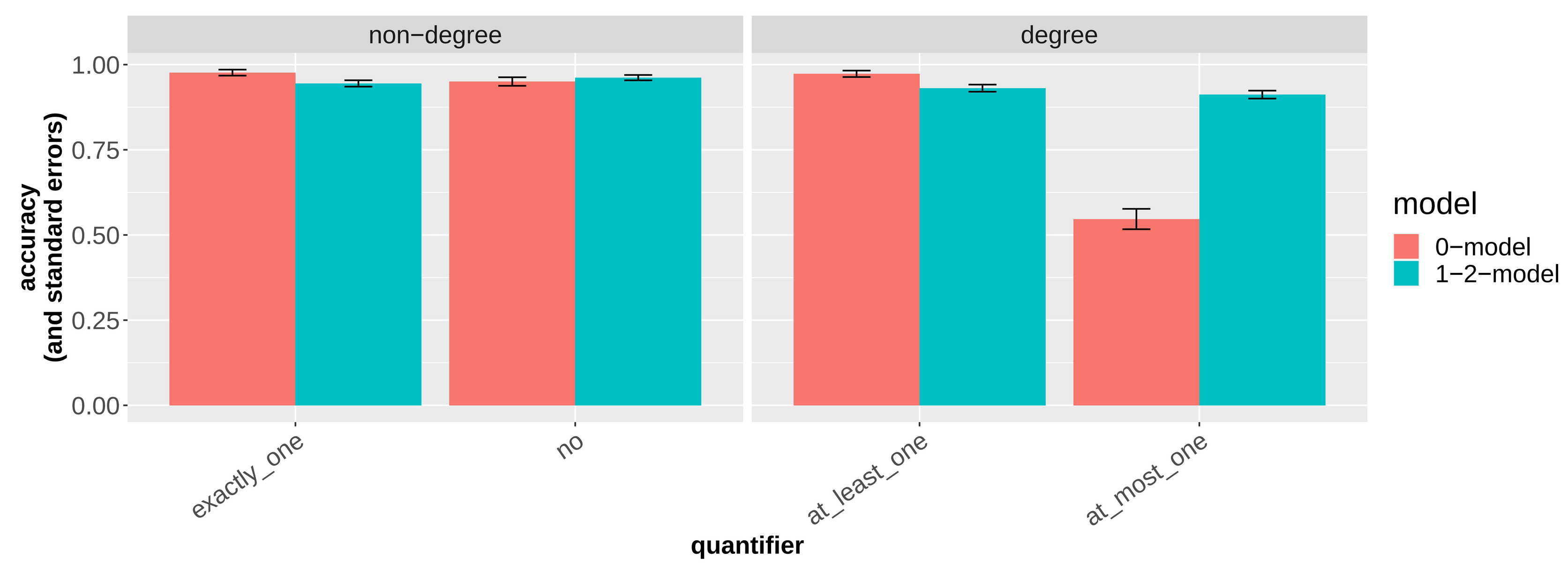
- 2 QUANTIFIER TYPES $\times$ 2 ES PROPERTY $\times$ 3 MODEL within design
  - QUANTIFIER TYPES: *degree* quantifiers (*höchstens ein* ('at most one') & *mindestens ein* ('at least one')) vs. non-*degree* quantifiers (*kein* ('no') & *genau ein* ('exactly one'))
  - ES PROPERTY: ES (*at most* & *no*) vs. non-ES QUANTIFIER (*at least* & *exactly*)
  - MODEL $\rightarrow$ zero, one, or two objects in mentioned color plus marked objects



(a) control 'exactly' (b) control 'no' (c) control 'at least' (d) control 'at most'

- In addition, 4 control conditions violate additive inference of *außer* ('besides')
- 64 experimental items in 16 conditions and 84 fillers across 16 lists

Results: ES quantifiers – accuracy

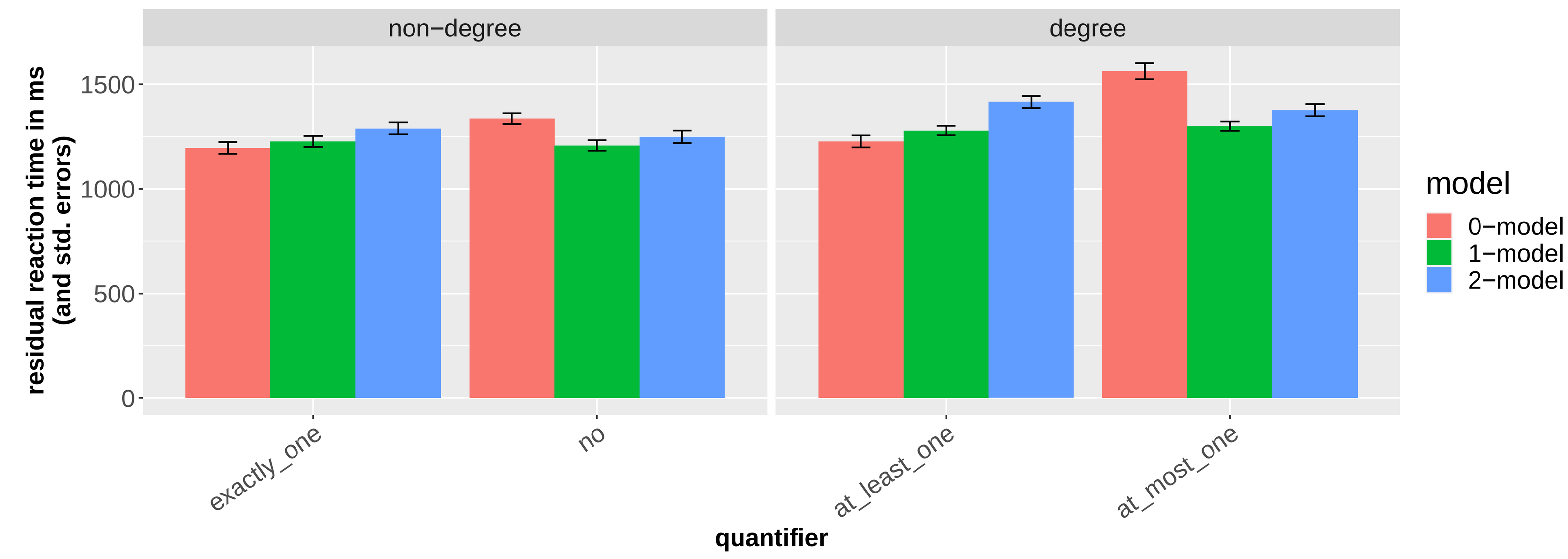


- Significant three-way interaction ($\chi^2(1) = 8.25, p = .004$), due to:
  - Lower accuracy in 0-model compared to other two models for *at most one* ($\beta = -1.32, z = -10.6, p < .001$)
  - No difference for *no* ($\beta = -0.15, z = -0.84, p = .4$)
  - No difference for other two quantifiers ($\beta = 0.47, z = 2.43, p = .015; \beta = 0.43, z = 2.11, p = .035$)

$\Rightarrow$ **ES effect in accuracy** for *degree* $\emptyset$ Q (*at most one*), non-significant for non-*degree* $\emptyset$ Q (*no*)

Results: ES-quantifiers – residual RT (corrected for response polarity)

- Significant three-way interaction ($\chi^2(2) = 6.31, p = .042$)
- In both QUANTIFIER TYPES predicted two-way interaction between ES PROPERTY and MODEL (*degree*: $\chi^2(2) = 53.09, p < .001$; *non-degree*: $\chi^2(2) = 18.22, p < .001$)
- Reason for interactions
  - $\neg\emptyset$ Qs: Additional objects in mentioned color increase RT (lowest RT in 0-*model*)
  - $\emptyset$ Qs: Longest RT in 0-*model* (ES situation)
  (0- vs. 1-model for *at most*: $t = 6.06, p < .001$; for *no*: $t = 3.94, p < .001$)



Results: Additive controls

- RTs in control conditions in range of longest RTs among target conditions ($1,500 - 1,650$ ms) but no significant differences ($\chi^2(3) = 6.13, p = .105$)
- Generally low accuracy ($47\% - 61\%$) but significantly higher for *no* as compared to other quantifiers (*at most one*: $\beta = -1.16, z = -3.87, p < .001$; *at least one*: $\beta = -0.87, z = -3.39, p < .001$; *exactly one*: $\beta = -0.70, z = -2.16, p = .031$).

Discussion & outlook

Target conditions (ES effects):

- Consistent **ES effects despite additional object in mentioned color**

$\Rightarrow$ **ES effects related to compositional meaning**, not only superficial features

- **Relatively small ES effects for *no*** consistent with previous results (Bott et al., 2019; Geurts et al., 2010)
- Another parallel to Bott et al. (2019): **extremely high error rate for *at most***

$\Rightarrow$ Interaction between ES property and compositional structure as encoded in semantic types ($< 1, 1 >$ vs. $< 1, 1, 1 >$ vs. $< 1, 1, 2 >$)?

Control experiment (interpretation of *außer*-sentences):

- Mixed judgments and hesitant RTs indicate **additive inference is presupposed** or non-at-issue (cf. Vostrikova, 2019a, 2019b)
- Relatively high accuracy of *no* may be due to interpretation as 'true' exceptive (e.g. Von Fintel, 1993) or alternatively indicate ES effect on its own

Exhausting the full compositional potential of combining domain subtraction with the ES property is theoretically challenging and empirically promising:

(4) ***All but at most n** A are B*

- 'Embedded ES effect' in situations where all A are B pushes distinction between lexical features and truth-values to extreme
- 'Global ES effect' possible in models with fewer than *n* elements in A, although quantifier is upward entailing

Selected References: Bott, O., Schlotterbeck, F., & Klein, U. (2019). *Journal of Semantics*, *36*(1), 99–163. Geurts, B., Katsos, N., Cummins, C., Moons, J., & Noordman, L. (2010). *Language and Cognitive Processes*, *25*, 130–148. Hunter, T., & Lidz, J. (2012). *Journal of Semantics*, *30*(3), 315–334. Just, M. A., & Carpenter, P. A. (1971). *Journal of Verbal Learning and Verbal Behaviour*, *10*(3), 244–253. Von Fintel, K. (1993). *Natural Language Semantics*, *1*(2), 123–148. Vostrikova, E. (2019a). Besides exceptives. In D. G. Maggie Baird & M. Nelson (Eds.), *Proceedings of NELS 49* (pp. 265–274). Vostrikova, E. (2019b). *Phrasal and clausal exceptive-additive constructions crosslinguistically* (Doctoral dissertation). UMass Amherst.