Reading times show effects of contextual complexity and uncertainty in comprehension of German universal quantifiers

Introduction: Current semantic and pragmatic theory offers detailed models of meaning-related processes in a wide range of linguistic phenomena. In addition to classical approaches, these models do not only intend to explain the compositional derivation of sentence meaning in general, but also focus on phenomena like incremental meaning composition [e.g. 1], the complexity of meaning representations ([e.g. 2, 3]) and contextual effects on the behavior of speakers and listeners [e.g. 4, 5]. Despite these recent advances, relating predictions derived from semantic and pragmatic theory to processes during online comprehension remains elusive up until today, while theory-driven syntactic considerations have been implemented into models of on-line sentence comprehension for decades. This is especially surprising as highly comparable linking hypotheses could be developed on the basis of recent semantic and pragmatic models. For example, one could assume that complex meaning representations are generally avoided, or that highly expected sentence continuations lead to facilitation during incremental processing. We attempt to bridge this gap by studying how complexity and uncertainty in sentence meaning affect on-line sentence comprehension. To this end, we examined how restrictive processes incrementally interact with other aspects of quantifier meaning, comparably to previous studies [6, 7]. In the current experiment, we combined self-paced reading with picture-sentence verification to test how reading times are affected by meaning-related processes.

Methods: In each trial of the current self-paced reading experiment (N = 41), participants first inspected a picture context showing geometrical objects inside and outside of a container shape (one of the Fig. in 1a-1d) and then read a German universally quantified sentence as in example (1-a-c). Half of the sentences contained a restrictive relative clause, which could lead to a possible meaning change by introducing a particular subset reading. Sentences were presented word-by-word (with punctuation displayed separately) using the moving-window technique, and participants then performed a truth-value judgment task. For sentences following the simple contexts 1b and 1c, a truth-value judgment is possible already on the color adjective whereas, with contexts 1a and 1d, the judgment has to be delayed until the preposition is encountered. If we additionally assume that, by default, participants expect true utterances [6], their expectations would diverge between contexts 1b vs. 1c on the color adjective and between contexts 1a vs. 1d on the preposition. Based on these considerations as well as conclusions from previous studies, we predicted an effect of truth value on the color adjective in the former (context 1b vs. 1c) and on the preposition in the latter conditions (context 1a vs. 1d). To test for effects of pictorial complexity and truth values, we statistically analyzed reading times on the color adjective and the preposition of the restricted sentences using a linear mixed effects model. As fixed effects the model included the factors PICTURE COMPLEXITY (levels simple (1b, 1c) vs. complex (1a, 1d)) and GLOBAL TRUTH VALUE (levels true vs. false) in a 2x2 factorial design. Note that in this analysis contexts such as 1a and 1d were aggregated on the color adjective according to the GLOBAL TRUTH VALUE of the specific sentence-picture combination and the two prepositions were also aggregated.

Results: Across conditions, truth-value judgments were correct in the majority of cases ($87.1\% - 91.9.8\%$). Word reading times are shown in Fig 2. PICTURE COMPLEXITY led to significantly longer reading times. These effects were sustained over several regions and turned out to be reliable on the color adjective ($t = 2.331, p = .022$) as well as on the preposition ($t = 5.982, p < .001$). In contrast, GLOBAL TRUTH VALUE affected reading times only after a truth-value judgment was possible (PICTURE COMPLEXITY $\times$ GLOBAL TRUTH VALUE interaction on the colour adjective: $t = 1.928$ (pairwise comparisons: $t = 2.504$ vs. $t = 0.169$ in the simple and complex conditions, resp.); main effect of GLOBAL TRUTH VALUE on the preposition: $t = 1.741, p = 0.0819$).

Discussion: The current results showed that picture complexity and truth values affected reading times in the expected direction. First, with regard to the complexity effect, we assume that a theory that describes how representations of context in memory affect the online construction of meaning representations could offer a plausible explanation for this finding. While we are not aware of such a theory, we think memory-

based approaches to syntactic processing could be instructive [e.g. 8, 9]. Second, in line with previous ERP results [e.g. 6], the truth-value effect on the colour adjective could either reflect a local truth evaluation, or, alternatively, a facilitation of sentence continuations that are expected because they still allow for true descriptions of the context. To distinguish between these two types of explanations, we are currently conducting a follow-up experiment using pictures like shown in Figures 1e and 1f, in which one triangle is colored differently, e.g. yellow instead of red. In such pictures, no truth-value judgment is possible on the adjective but, in contrast to the complex pictures in Fig. 1a and 1d, the actually presented colour adjective (e.g. *blue*) is the only one that still allows for true sentence completions in our design. Results form this follow-up will also be informative with respect to the potential role of salience, e.g. of colour terms primed by the picture contexts. In sum, by investigating quantifier restriction in a self-paced reading task, the current study showed that meaning-related processes may incrementally affect on-line sentence comprehension. Together with our planned follow-up studies, the current study is intended to be the basis for implementing formal-pragmatic and semantic considerations on theories of on-line sentence comprehension.

(1) a.   Alle Dreiecke sind blau, die innerhalb des Kreises sind.
          All triangles are blue that inside of_the circle are

    b.   Alle Dreiecke sind blau, die außerhalb des Kreises sind.
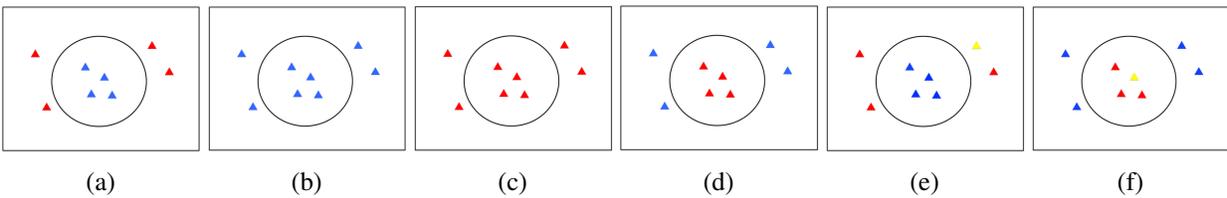   All triangles are blue that outside of_the circle are

    c.   Alle Dreiecke sind blau

(a)	(b)	(c)	(d)	(e)	(f)

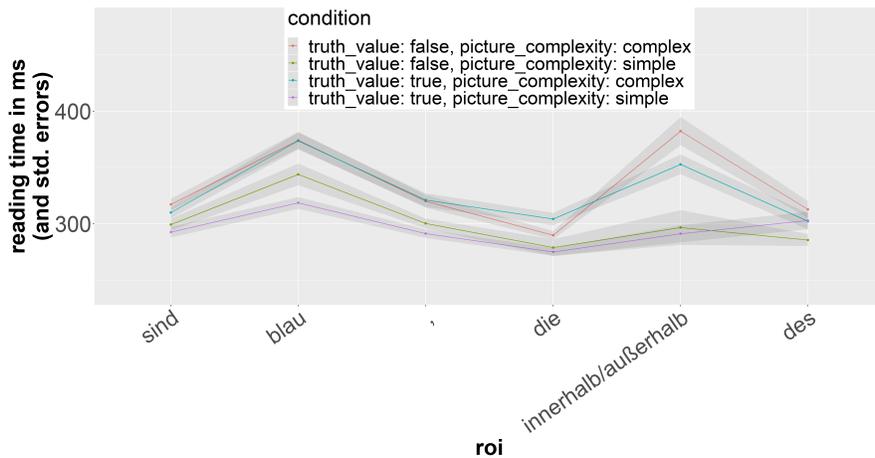Figure 1: Picture contexts used in the current (1a-1d) and follow-up experiment (1a-1f)

Figure 2: Reading times in regions 3 to 8 (conditions aggregated)

References:

1. Bott, O. et al. *J Semant* **34,** 201–236 (2017). 2. Pietroski, P. et al. *Mind and Language* **24,** 554–585 (2009). 3. Szymanik, J. *Quantifiers and Cognition. Logical and Computational Perspectives* (Springer, 2016). 4. Frank, M. C. et al. *Science* **336,** 998–998 (2012). 5. Van Tiel, B. et al. *PNAS* **118** (2021). 6. Augurzky, P. et al. *Lang Cog* **9,** 603–636 (2017). 7. Augurzky, P. et al. *Cognitive Sci* **43** (2019). 8. Lewis, R. et al. *Cognitive Sci* **43,** 375–419 (2005). 9. Futrell, R. et al. *Cognitive Science* **44** (2020).