Predictions beyond the word: Evidence for morpheme-level incrementality from cognitive modeling and eye-tracking

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Visual world studies have shown that word recognition is highly incremental, with listeners using sublexical features as the speech signal unfolds [1]. By contrast, computational models and empirical studies of word prediction typically assume word-level processing, with predictions being updated only after a full word has been processed [2-4]. This overlooks the possibility that predictions may be additionally driven by sublexical information. We examined whether predictions are updated incrementally at the morpheme or at the word level by comparing two cue-based retrieval models [5] that shared the same underlying assumption: predictions are cue-based memory retrievals [2]. Crucially, the models differed only in the level of granularity for predictions: word-level [2] versus morpheme-level [6].

Visual world eye-tracking experiments. We tested 89 German speakers in two experiments using morphologically complex adjectives consisting of a semantically informative stem and a gender-marked suffix (see (1)). In **EXP. 1**, subjects viewed two objects while hearing German instructions like (2). The target matched the adjective stem (color cue) and suffix (gender cue). Interference was manipulated via the competitor: unambiguous (mismatching both cues), gender-interference (matching the suffix cue only), and color-interference (matching the stem cue only). In **EXP. 2**, subjects viewed greyscale, gender mismatching objects while hearing instructions like (3). Here, the semantic cue relied solely on adjective-object association strength. Interference was manipulated via this association: in the low-interference condition, the adjective stem was strongly associated with the target but not with the competitor (‘hot coffee’ vs. ‘hot ice cream’); in the high-interference condition, the adjective was changed to favor the competitor (‘cold ice cream’), which was strongly associated with the competitor but only weakly with the target. Prediction onsets were extracted using a GAMM-based method [7].

Results. For Exp. 1, the word-level model predicted similar prediction onsets across conditions, whereas the morpheme-level model predicted a delayed onset in the color-interference condition due to this model allowing activation to spread already after the adjective stem; in the color-interference condition, this results in equal activation of both objects. Eye-tracking data supported the morpheme-level model (Fig. 1). For Exp. 2, the word-level model predicted no difference across conditions while the morpheme-level model predicted a delay with a temporary preference for the competitor before the target prediction. Eye-tracking data again supported the morpheme-level model (Fig. 2). Overall, these results support sublexical predictive processing and highlight the need of theories that reflect this granularity, which is especially relevant in morphologically rich languages like German.

References

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Figure 1. Experiment 1: (A–B) Model-predicted fixation probabilities from [3] and [6]; (C) empirical fixation curves with 95% CI.

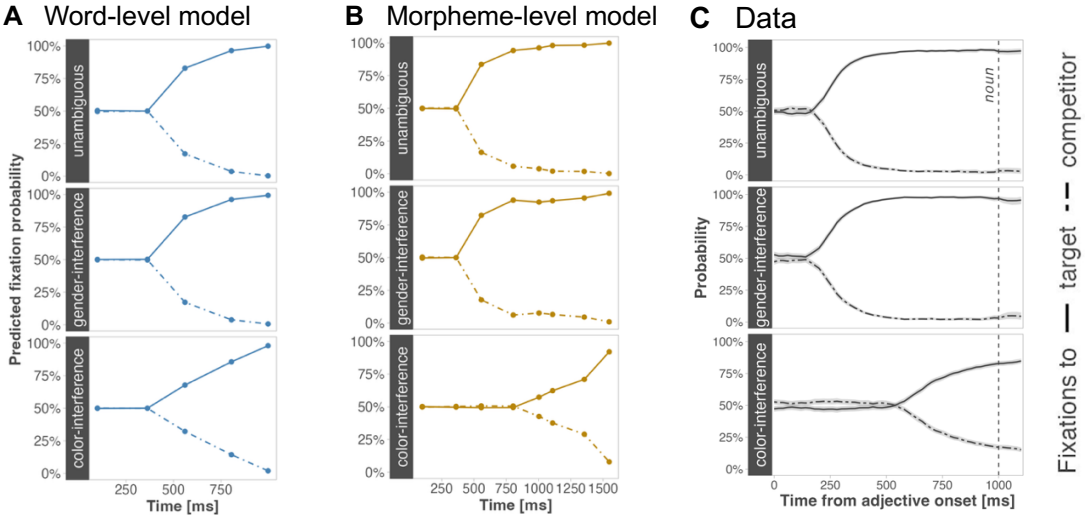
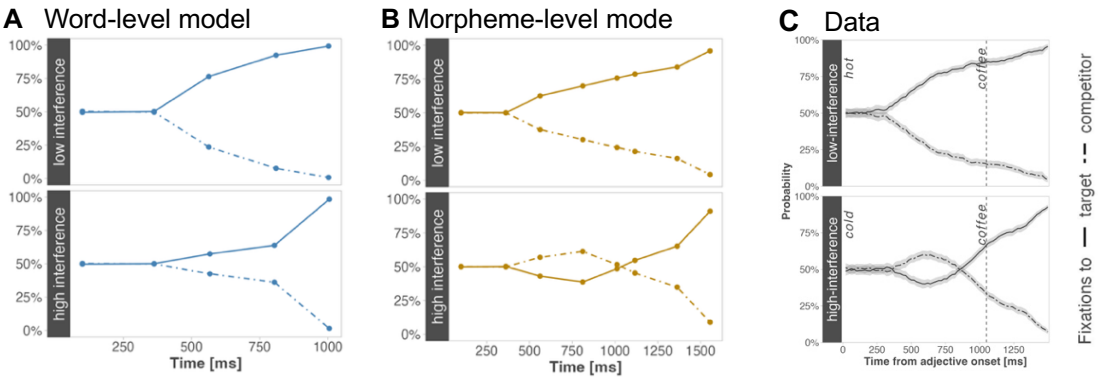


Figure 2. Experiment 2: Same structure as Figure 1.



Supplementary Information

(1) *The German adjectives used in the Experiments 1 and 2 comprise at least two morphemes. The stem morpheme (e.g. blue.*$_{BLUE}$, shown in blue below*) encoded a semantic cue that could be used during processing to predict the upcoming noun. The suffix morpheme (e.g. -er.*$_{NOM.MASC}$*, shown in black below) encoded a morphosyntactic gender cue that could be used to predict the upcoming noun since German agreement rules specify that adjectives and nouns should agree in gender.*

Da ist ein blauer Ballon!

There is a blue.$_{MASC}$ *balloon.*$_{MASC}$*!*

(2) Linguistic stimuli for Experiment 1

Da ist ein blauer Ballon!

There is a blue.$_{MASC}$ *balloon.*$_{MASC}$*!*

(3) Linguistic stimuli for Experiment 2

<u>Low-interference condition</u>

Da ist ein heißer Kaffee!

There is a hot.$_{MASC}$ *coffee.*$_{MASC}$*!*

<u>High-interference condition</u>

Da ist ein kalter Kaffee!

There is a cold.$_{MASC}$ *coffee.*$_{MASC}$*!*