How antecedent retrieval influences prediction: a cue-based retrieval model

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In contrast with English possessives like "his/her", German possessives such as "seinen" show a bi-directional pattern of agreement: The stem "sein-" indicates a preceding masculine possessor (like English "his") but additionally, the suffix "-en" indicates an upcoming masculine possessum. These backward- and forward-looking agreement relationships mean that German comprehenders can use the gender features of a possessive to both retrieve an antecedent—a memory search process [1]—and to predict an upcoming possessum—a predictive process [2,3]. Thus, German possessives provide a good test case to examine whether retrieval and predictive mechanisms interact during processing. Stone et al. (2020) addressed this question in a visual-world study and reported an interaction between these mechanisms, such that participants' predictions of the upcoming possessum were faster when the possessum and possessor matched in gender (match condition) than when they mismatched (mismatch condition) [4]. Here, we propose a computational model of these findings, which extends the cue-based retrieval architecture proposed in [5] (henceforth CBR) and further proposes that the faster prediction in the match condition is due to similarity-based interference during the antecedent retrieval process.

Data. In a visual-world study, participants heard a German auditory instruction with a possessive pronoun, e.g. "*Click on his/her blue button*", while seeing a target object and a competitor with different gender on the screen ([4]: Experiment 2; see *Materials and results*). Masculine and feminine possessives were counterbalanced across the experimental conditions, such that "sein" appeared in half of the mismatch trials and "ihr" in the other half. The findings were: (i) The existence of anticipatory looks to the target object before its mention, during the adjective time window; (ii) the earlier onset of predictions when the possessor and target object matched in gender, as estimated by a bootstrapping approach [6]. The anticipatory looks to the target due to gender-marking are consistent with previous studies [2,3], but the modulation of the prediction onset due to the (syntactically irrelevant) gender of the possessor is surprising and cannot be explained by existing theories of predictive processing.

Modelling. The CBR architecture has been used in the past for modeling the pronoun-antecedent retrieval process [7,8]. It has also been extended to model eye fixations in a sentence-picture matching task [9]. We combined these two approaches in ACT-R [10] such that the antecedent retrieval process was carried out as per the standard CBR architecture, while the possessum prediction was carried out as a retrieval of the target picture's memory representation (see *Appendix*). We propose that the probability of fixating on pictures in a visual-world task is determined by their relative activation in memory.

Results & discussion. The model captures the two key effects in the data: (i) the prediction of the target object before hearing its name, and (ii) the earlier onset of prediction in the match than mismatch condition (see *Figure*). The model captures (i) by using the gender and color features of the possessive and adjective to retrieve the target object (e.g. "masculine" and "blue"). The model captures (ii) through an interaction between retrieval and prediction processes. Specifically, the gender cue in the antecedent retrieval in the match condition boosts the activation of objects in memory that match this gender cue, including the possessum, i.e. the target picture (a similarity-based interference effect). On the other hand, the gender cue in the antecedent retrieval in the mismatch condition boosts the activation of the competitor picture but not the target picture. This difference in activation at the possessive leads to a prediction advantage in the match condition. Thus, our model proposes that retrieval interference in the resolution of the pronoun-antecedent dependency influences the prediction of the following possessum.

Materials and results

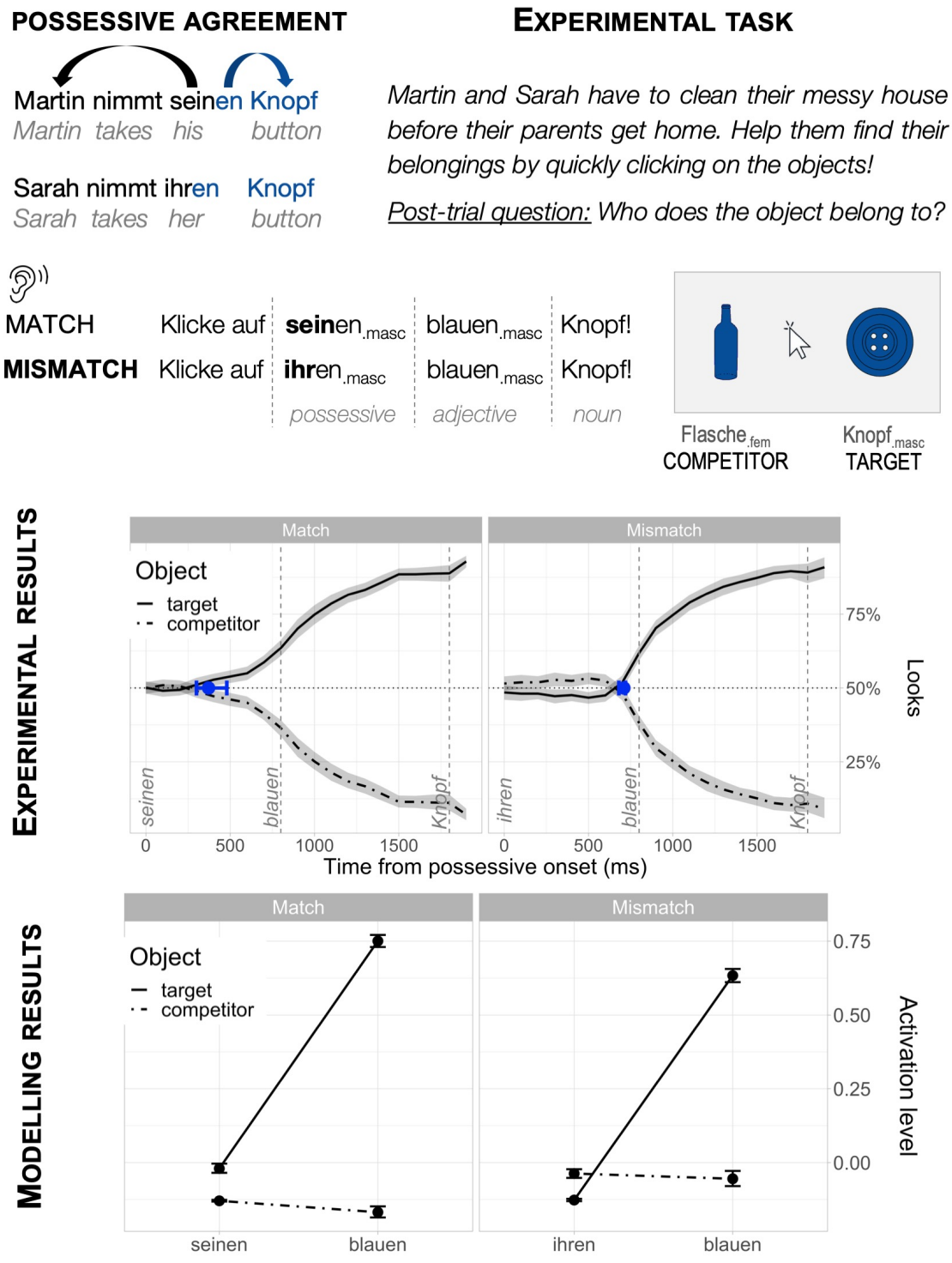

Figure. *Experimental results*: Percentage of looks to each object in Experiment 2 [5]. Blue circles denote the earliest point when target and competitor diverged together with bootstrapped 95% confidence intervals. The divergence onset (blue circles) was delayed on average 318 [200-400] ms in the mismatch condition. *Modelling results*: Activation levels of the two objects on the screen after processing the possessive and the adjective (2000 simulations per condition). Due to antecedent retrieval, the target object was more activated than the competitor already after processing the possessive in the match condition.

Appendix with details about the computational model

Model assumptions

In order to account for the data reported in [5], the following assumptions were added to the model to extend the original CBR theory.

1. At each input word, the model tries to predict the target picture (the possessum) based on the information in the sentence encountered up to this point in time.
2. The target picture prediction is implemented as the cue-based retrieval of the memory representation of this picture. Additionally, the cues used for retrieval were weighted, such that color cues were weighted more highly than the linguistic cues. This was done to reflect the importance of visual over linguistic features due to the nature of the visual world task.
3. At the onset of the possessive pronoun the antecedent is first retrieved and then the target picture is predicted.
4. The activation level of the memory representations of a picture corresponds to its fixation probability.

ACT-R parameter values

List of ACT-R parameter values that were modified for our model. All other parameters had their default values.

Name (ACT-R parameter)	Default value	Modified value
Activation noise (ANS)	0.2	0.15
Maximum associative strength (MAS)	1	3
Match Scale (MP)	1	0.25

References

[1] Corbett & Chang (1983) *Memory and Cognition*. **[2]** Hopp & Lemmerth (2018) *Studies in Second Language Acquisition.* **[3]** Grüter, Lew-Williams, & Fernald (2012) *Second Language Research.* **[4]** Stone, Oltrogge, Vasishth & Lago (2020) *CUNY 2020.* **[5]** Lewis & Vasishth (2005) *Cognitive Science*. **[6]** Stone, Lago & Schad (under review) *Bilingualism: Language and Cognition.* **[7]** Jäger, Engelmann & Vasishth (2015) *Frontiers in Psychology.* **[8]** Patil, Vasishth, & Lewis (2016) *Frontiers in Psychology.* **[9]** Patil, Hanne, Buchert, De Bleser & Vasishth (2016) *Cognitive Science.* **[10]** Anderson et al., 2004, *Psychological Review.*