# SYNTACTIC CATEGORY FACILITATES RATHER THAN INHIBITS LEXICAL COMPETITION

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## ABSTRACT

In this study we address whether contextual constraints impact word recognition in the same way that bottom-up phonological information does. Standard models of word recognition assume that cohort competition arises when auditory input increases the activation of word-forms with matching phonological features. Previous work on syntactic category effects has focused on how quickly syntactic context might constrain lexical competition, but findings have varied. In addition, no study has been able to distinguish between an inhibitory and a facilitatory mechanism for the constraint. We examine this with a novel design for the visual world paradigm that allows us to make this distinction. We find phonological competition from syntactically inappropriate candidates, in a pattern consistent with a facilitatory rather than an inhibitory mechanism for contextual constraint. This suggests that the constraint operates analogously to and cannot override bottom-up auditory input.

**Keywords**: syntactic category, word recognition

## 1. INTRODUCTION

During auditory word recognition, speech input activates stored phonological word-forms that are consistent with the sounds that have been perceived. Because of the incremental nature of auditory lexical processing and the fact that many word-forms share the same initial phoneme, massive subsets of the lexicon are assumed to be activated at the acoustic onset of a word, before the input is sufficiently constraining for the word to be identified. It has been well established that word recognition proceeds more quickly and more accurately when it occurs in context of any sort. It would seem that the reason context is helpful is that it (at least) provides additional information that can reduce the size of the set of lexical candidates; for example, nouns are better candidates than verbs after hearing the word "the." But a great deal of work investigating this possibility over the years has led to disagreement over whether context can actually do more than this, and impose its constraints so quickly that contextually inappropriate lexical candidates are never considered at all. In this paper we will focus on whether and *how* syntactic category information, specifically, might have this early or even immediate effect. Methods like cross-modal priming and gating have tended to indicate that the constraint is not immediate, because they provide evidence for initial lexical competition from words of the wrong syntactic category [4,5]. Experiments in the visual world paradigm, however, have demonstrated immediate effects of syntactic context such that wrong-category items never appear to compete [2,3].

Independent of the timing question, there has been little discussion of the mechanism for the constraint. It has not been possible for these designs to provide evidence that indicates whether the constraint occurs by increasing the activation of syntactically appropriate candidates (facilitation) or eliminating the activation of those that are syntactically inappropriate (inhibition). This distinction matters because, if the constraint is facilitatory, the detection of wrong-category cohort competition should not be taken as evidence against the presence of the constraint. In this work, we will describe a novel design that makes distinct predictions for these two possibilities, using eye-tracking in the visual world paradigm. With this design, we detect phonological competition whether or not the competitor is appropriate for the syntactic context. This is consistent with the predictions of a facilitatory rather than inhibitory mechanism for contextual constraint.

## 2. DESIGN & PREDICTIONS

### 2.1. Facilitation vs. inhibition

The fundamental manipulation in our study used a grid of four pictures with noun-only names. None shared an onset (e.g. *balcony*, *moustache*, *curtain*, *wheelbarrow*). One second after grid presentation, a sentence containing a noun-only target (e.g. "battleship") was presented auditorily. For example: "He chose the battleship for his birthday." The auditory target was a phonological onset

competitor of one of the pictures (here, of *balcony*); the remaining pictures are considered distractors. We then measured the proportion of fixations to each of the four pictures following the onset of "battleship." Looks to the balcony were expected to increase relative to baseline, roughly 200 to 400 ms after the onset of "battleship."

This was counter-balanced such that for half of our participants, the auditory sentence frame for that trial instead constituted a verb context, and contained a verb-only target. For example: "He chose to bask in the sun." An identical grid was presented, and we measured the proportion of fixations to each of the four pictures following the onset of "bask." The critical question was whether looks to the balcony would increase during "bask," relative to baseline, as they were expected to during "battleship." Each participant saw half of the grids with a noun context and half with a verb context.

A category constraint acting via total inhibition of wrong-category candidates should stop bottom-up activation of *balcony* (N) in the context of "to bask" (V), such that fixations do not increase relative to baseline. However, a constraint acting via facilitation of correct-category candidates should not stop bottom-up activation of *balcony* (N) in the context of "to bask" (V), meaning that fixations to the balcony (N) should still increase relative to baseline, just as they do in the context of "the battleship" (N). Furthermore, during "the battleship" (N) all four noun items would be expected to receive equal facilitation due to their category, so the proportional increase for the competitor due to bottom-up input would not be different from in the verb context.

These critical trials meant to elicit a competition effect did not include a target. Huettig & McQueen [1] have shown that this is a valid and even desirable design choice if properties of the competition effect are what is under study. Not including a target in the critical trials meant that only activation changes from the competitor could be expected to lead to changes in fixation probability, and that the magnitude of the competition effect should be larger because the target would not draw any probability. It also meant that the traditional task in the visual world paradigm ("Look at the…") would not make sense. Instead, after each trial, we had participants indicate whether or not they had seen anything on the screen related to what they were hearing.

### 2.2. Constraint timing

In the case of a facilitatory constraint, the manipulation described in section 2.1 predicts no difference between competition in noun and verb contexts, which would make the timing of the constraint impossible to see. We therefore included a second manipulation which was expected to demonstrate a difference between noun and verb contexts as soon as the constraint applied, regardless of the mechanism. As above, four pictures were presented (e.g. *soap*, *drawer*, *camel*, *triangle*), none sharing an onset. Three of the pictures had noun-only names, and the fourth picture's name could be used as a noun or a verb, but was strongly noun biased. One second after grid presentation, a sentence containing a noun-only target (e.g. "sofa") was presented auditorily. For example: "He neglected the sofa in the playroom." The auditory target was a phonological onset competitor of the picture whose name could be a noun or a verb (here, *soap*, useable as a verb in e.g. "He neglected to soap his hands thoroughly"). The remaining pictures are distractors. We measured the proportion of fixations to each of the four pictures following the onset of "sofa," with looks to the soap expected to increase relative to baseline roughly 200 to 400 ms after the onset of "sofa."

This was counter-balanced so that for half of our participants, the auditory sentence frame was a verb context, and contained a verb-only target. For example: "He neglected to socialize the puppies when they were young." An identical grid was presented, and we measured the proportion of fixations to each of the four pictures following the onset of "socialize" rather than "sofa." The critical question was whether looks to the soap would increase during "socialize," relative to baseline, as much as they did during "sofa."

A category constraint acting via inhibition of wrong-category candidates should inhibit activation of *soap* (N/V) in the context of "to socialize" (V) more than it should inhibit activation of *soap* (N/V) during the context of "the sofa" (N), because *soap* is used less often in verb context than noun context, and we assume that such a category constraint would operate proportionally with respect to frequency. We would then expect to see more fixations to the soap during "sofa" than during "socialize." A category constraint acting via facilitation of correct-category candidates should, we think, have indistinguishable effects. *Soap* should be facilitated in the context of "to socialize" just as in the context of "the sofa," but simply to a lesser extent.

### 2.3. Fillers

We included fillers so that in half of the trials one of the picture names would actually be mentioned in the sentence. Half of our filler trials operated identically to the noun-context trials in the first manipulation, except that the competitor picture became the auditory target, and one of the three noun-only distractors was replaced

with a noun-verb picture. The other half of our filler trials operated identically to the verb-context trials in the second manipulation, with one noun-verb picture and three noun-only pictures, except that the noun-verb picture was the target instead of a competitor. For example, the four pictures would be: *soap*, *pineapple*, *tractor*, *fireplace*. The auditory sentence would be "He neglected to soap his hands thoroughly." Participants were expected to answer "yes" to the ensuing prompt asking them whether they had seen anything that was related to what they were hearing. These trials were necessary to ensure that participants had motivation to look at the pictures in verb context. All stimuli are available in the supplementary materials.

## 3. METHOD

### 3.1 Procedure

We used a tower-mounted SR Research Eyelink 1000 to record eye movements. In each of the 120 trials, a 3x3 grid appeared on the screen with a picture in each of the four corners. The grid was displayed for 1000 ms before the sentence started playing and disappeared when the sentence ended. This was always followed by the question, "Did you see anything on the screen related to what you were hearing?". The next trial would start after the participant had answered the question and a drift check was performed.

### 3.2 Sample size & power

We used a conservative effect size estimate of 0.4, based on Huettig & McQueen's [1] phonological competition effect for noun pictures in noun context. Power analysis indicated that to achieve 80% power for an interaction in which the competition effect was present in noun context but not in verb context (as could be expected if the effect was inhibitory), a sample size of 164 was required. We report results from 125 participants so far; another 15 datasets have been excluded due to equipment failure or dual language exposure. We plan to collect data until we have a fully counter-balanced, analyze-able set of 144.

### 3.3. Analysis

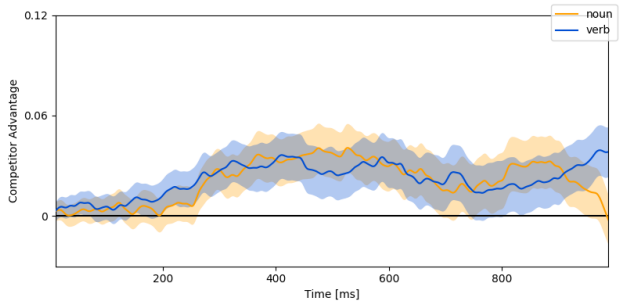
We extracted fixations that occurred during a 400 ms window time-locked from the onset of the context word (to/the) and a 1000 ms window time-locked from the onset of the critical word. For each participant and condition, for each time point in these two time-courses, we calculated the proportion of instances of this time point across trials in which the competitor was fixated. Then, for each participant and condition we computed the mean proportion of fixations to the competitor in the first 100 ms of the context word. We subtracted this baseline from the proportion of fixations at each time point in the critical window to create a "competitor advantage" reflecting any increase in the proportion of fixations to the competitor relative to a time window when looks could not have been driven by the difference between conditions. We then smoothed the data using a 20 ms Hamming window. The time-courses of the competitor advantage for each participant were submitted to temporal cluster tests.

For the critical conditions, the temporal cluster tests were related-measures *t*-tests to determine whether there was a difference in the time-course of the competitor advantage between the noun and verb contexts. This was done separately for noun-only competitors and noun-verb ambiguous competitors. We then conducted pairwise follow-up one-sample *t*-tests against zero, asking when there was a reliable competitor advantage within each context. Temporal cluster tests were always one-tailed and conducted with 10,000 permutations and a threshold of $p < 0.05$ for forming clusters. The critical time window in which we expected robust competition was 100 to 550 ms, based on Strand et al. [3] and Huettig & McQueen's [1] results.

## 4. RESULTS

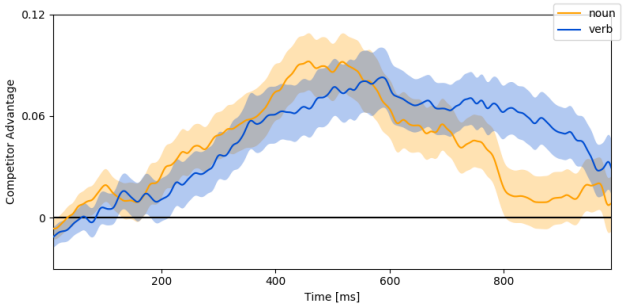
For the noun-only competitors (Figure 1) there were no clusters indicating a difference in the competitor advantage between the noun and verb contexts. Follow-up one-sample *t*-tests in each context in the critical window indicate significant clusters in which the competitor advantage differs from zero in the noun context, from 274 to 550 ms ($p < 0.05$), and in the verb context, from 257 to 509 ms ($p < 0.05$).

**Figure 1:** Time-course of competitor advantage relative to baseline for the noun-only competitor, in noun and verb contexts.



For the noun-verb ambiguous competitors (Figure 2) there were also no clusters indicating a difference in the competitor advantage between the noun and verb contexts. Follow-up one-sample *t*-tests in each context in the critical window indicate significant clusters in which the competitor advantage differs from zero in the noun context, from 194 to 550 ms ($p < 0.05$), and in the verb context, from 243 to 550 ms ($p < 0.05$).

**Figure 2:** Time-course of competitor advantage relative to baseline for the noun-verb ambiguous competitor, in noun and verb contexts.




## 5. DISCUSSION

The fundamental question in this experiment was whether or not noun-only cohort competitors would show evidence of competition when they were inconsistent with the syntactic context. Previous work in the visual world paradigm [2,3] indicated that they would not, but this conflicted with evidence from cross-modal priming [4] and gating [5]. We designed the study to differentiate between facilitatory and inhibitory mechanisms for the context constraint, and to avoid any potentially confounding strategies available to participants in previous experiments, such as the use of action pictures as referents for verbs.

In our first manipulation, comparing cohort competition from noun-only competitors in noun and verb contexts, we found that noun-only cohort competitors *do* compete when they are syntactically inappropriate; the proportion of fixations to the noun-only cohort competitor increased significantly over baseline by 275 ms after word onset in both noun and verb contexts. We found no evidence for a difference in the "competitor advantage" between the two contexts. This result rules out an immediate inhibitory category constraint, making facilitation of correct-category candidates more likely.

Our second manipulation was intended to provide evidence about the timing of the constraint. Whether or not the constraint operates via facilitation or inhibition, the noun-verb ambiguous cohort competitor should be affected differentially from its noun-only distractors, such that we should see a difference between noun and verb contexts once the constraint applies. Specifically, because our cohort competitors were vastly more frequent in noun contexts than verb contexts, we should see a larger competitor advantage in noun contexts.

So far, with an incomplete sample, we observe robust cohort competition in both the noun and verb contexts. We find that the competitor advantage is always larger in the noun context than in the verb context in the time window of interest, but this is not a statistically significant difference. If this remains the case at the end of data collection, this trend will need to be followed up on in future research. We do note that the competition effect begins 49 ms earlier in the noun context.

If there turns out to be a reliable difference between the contexts, the timing of this difference is important for our interpretation of the constraint. Already, we can rule out one corner of the hypothesis space: that wrong-category competitors are not generated. Our data show that they are generated and they do compete. If the noun-verb ambiguous condition indicates an immediate context difference, we will interpret this to mean there is an immediate facilitatory effect on competitors that are consistent with the syntactic context. A later context effect for the ambiguous manipulation will indicate that that facilitatory effect is delayed.

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