SYNTACTIC CATEGORY DOES NOT INHIBIT LEXICAL COMPETITION

Phoebe Gaston, Ellen Lau, and Colin Phillips

University of Maryland, College Park
pgaston@umd.edu, ellenlau@umd.edu, colin@umd.edu

ABSTRACT

In this study we address whether contextual constraints can override bottom-up phonological information during auditory word recognition. 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 whether syntactic context can prevent lexical competition, but findings have varied, and 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 do find 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, auditory 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 also been well established that word recognition proceeds more quickly and more accurately when it occurs in context of any sort. It seems likely that one of the reasons context is useful is that it can provide additional information that helps narrow down 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 in fact 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 conclude that the contextual constraint is not immediate, because they provide evidence for initial competition from words of the wrong syntactic category [5,6]. Experiments in the visual world paradigm, however, have demonstrated immediate effects of syntactic context such that wrong-category items never appear to compete [3,4].

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 while inappropriate candidates compete as usual (facilitation), or fully eliminating the activation of syntactically inappropriate candidates such that they are prevented from competing at all, while appropriate candidates compete as usual (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 their baseline level roughly 200 to 400 ms after target onset. Such an effect should occur regardless of whether nouns are facilitated or verbs are inhibited.

This condition was counter-balanced such that for half of our participants, the auditory sentence frame for that trial was instead 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 in the context of "to bask" (V) would only apply to verbs and so should not affect bottom-up activation of *balcony* (N), meaning that fixations to the balcony (N) should still increase relative to baseline.

These critical trials meant to elicit a competition effect did not include a target. Huettig & McQueen [2] 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. *scorpion*, *kitchen*, *dragonfly*, *bread*), 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 according to category-tagged frequency counts in the SUBTLEX-US corpus [1] (with a range of noun bias from 69.98% to 99.84% and mean of 93.1%). One second after grid presentation, a sentence containing a noun-only target (e.g. "brownie") was presented auditorily. For example: "She chose the brownie for her snack." The auditory target was a phonological onset competitor of the picture whose name could be a noun or a verb (here, *bread*, useable as a verb in e.g. "She preferred to bread the chicken before frying it"). We measured the proportion of fixations to each of the four pictures following the onset of "brownie," with looks to the bread expected to increase relative to baseline roughly 200 to 400 ms later.

This was counter-balanced so that for half of our participants, the auditory sentence frame instead had a verb-only target. For example: "She chose to brighten the room with fresh paint." An identical grid was presented, and we measured the proportion of fixations to each of the four pictures following the onset of "brighten" rather than "brownie." The critical question was whether looks to the bread would increase during "brighten" as much as they did during "brownie."

A category constraint acting via inhibition of wrong-category candidates should inhibit activation of *bread* (N/V) in the context of "to brighten" (V) more than it should inhibit activation of *bread* (N/V) in the context of "the brownie" (N), because *bread* 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 bread during "brownie" than during "brighten." A category constraint acting via facilitation of correct-category candidates should, we think, have indistinguishable effects. *Bread* should be facilitated in the context of "to brighten" just as in the context of "the brownie," but simply to a lesser extent (though we do not investigate correlation with noun bias in this study).

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."

These trials were necessary to ensure motivation to look at the pictures in verb context, but the use of picture-able noun-verb homophones to accomplish this ensured that noun/verb referent status was not predictable from initial viewing of the pictures, which may be an issue in [4]. 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 and the task question appeared. 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 [2] 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 would be expected if the effect was inhibitory), a sample size of 164 was required. We report results from 144 participants; an additional 21 datasets were excluded due to equipment failure or dual language exposure.

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 window. 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 only have been driven by chance. We then smoothed the data using a 20 ms Hamming window.

At each time-point, one-tailed related-measures t-tests were used to determine whether there was a larger competitor advantage in the noun context than the verb context, separately for noun-only competitors and noun-verb ambiguous competitors. Temporal cluster tests with 10,000 permutations and a threshold of $p < 0.05$ for forming clusters were used to detect temporal clusters of significance. In the same manner we conducted pairwise follow-up one-sample t-tests against zero within each context, asking when there was a reliable competitor advantage. The critical time window in which we expected robust competition was 100 to 550 ms, based on Strand et al. [4] and Huettig & McQueen's [2] 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 264 to 550 ms ($p < 0.05$), and in the verb context, from 317 to 454 ms ($p < 0.05$).

Figure 1: Time-course of competitor advantage relative to baseline for the noun-only competitor, in noun and verb contexts.
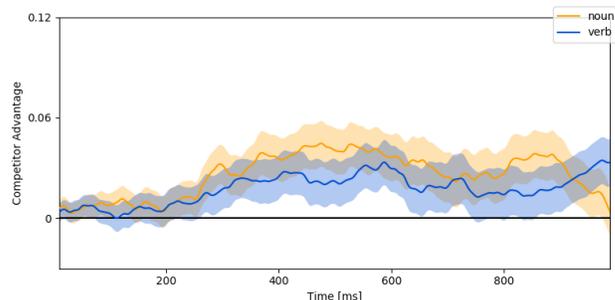
For the noun-verb ambiguous competitors (Figure 2) there were also no clusters indicating a difference in the

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 198 to 550 ms ($p < 0.05$), and in the verb context, from 270 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.
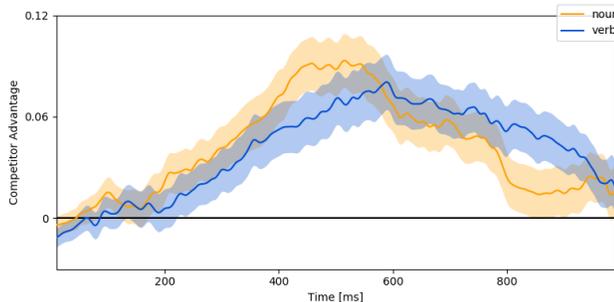
5. DISCUSSION

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 [3,4] suggested that they would not, but this conflicted with evidence from cross-modal priming [5] and gating [6]. 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 with the use of action pictures as referents for verbs in [4].

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 roughly 300 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. We suggest that the appearance of inhibition in previous studies may have been due to specific design choices.

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 was

expected to be affected differentially by the category information in the context, such that we would see a difference between noun and verb contexts once the constraint applied. Specifically, because our cohort competitors were much more frequent in noun contexts than verb contexts, we expected to see a larger competitor advantage in noun contexts.

However, while we observe robust cohort competition in both the noun and verb contexts, and find that the competitor advantage is generally larger in the noun context than in the verb context in the time window of interest, this is not a statistically significant difference. Because we were not able to estimate our power to detect this effect in advance, the expected noun/verb asymmetry will need to be followed up on in future research, especially given that our null effect is also consistent with a lack of category constraint altogether. If there turns out to be a reliable difference between the contexts in another method or design, the timing of this difference (i.e., whether it is immediate or not) will be 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, suggesting that top-down syntactic category information cannot override bottom-up auditory cues. Priority for bottom-up input would be desirable if contextual information is misheard or misinterpreted, or in the case of highly unexpected input.

REFERENCES

1. Brysbaert, M., New, B., & Keuleers, E. (2012). Adding part of-speech information to the SUBTLEX-US word frequencies. *Behavior Research Methods*, *44*(4), 991–997.
2. Huettig, F., & McQueen, J. M. (2007). The tug of war between phonological, semantic and shape information in language-mediated visual search. *Journal of Memory and Language*, *57*(4), 460-482.
3. Magnuson, J. S., Tanenhaus, M. K., & Aslin, R. N. (2008). Immediate effects of form-class constraints on spoken word recognition. *Cognition*, *108*(3), 866–873.
4. Strand, J. F., Brown, V. A., Brown, H. E., & Berg, J. J. (2018). Keep Listening: Grammatical Context Reduces but Does Not Eliminate Activation of Unexpected Words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44*(6):962-973
5. Tanenhaus, M. K., Leiman, J. M., & Seidenberg, M. S. (1979). Evidence for multiple stages in the processing of ambiguous words in syntactic contexts. *Journal of Verbal Learning and Verbal Behavior*, *18*(4), 427–440.
6. Tyler, L. K. (1984). The structure of the initial cohort: Evidence from gating. *Perception & Psychophysics*, *36*(5), 417–427.