# Competitor Activation and Semantic Interference: Evidence from Combined Phonological and Semantic Similarity

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**Abstract**

Incremental learning explanations state that semantic interference is driven by activation levels of competitors. To explore nonsemantic contributions to interference, we examined the combined and separate effects of facilitatory phonological form preparation and semantic relatedness in a blocked cyclic picture naming procedure. Phonological similarity was facilitatory when tested separately, but had little effect when tested with the other conditions. We found about twice as much interference in word sets that shared both meaning and form (e.g., cyclically name *puffin*, *pigeon*, and *peacock*) as in semantic-only sets. Thus, phonological similarity impacted interference when it was combined with a semantic attribute. A computational model that isolated the learning mechanism and eliminated carryover effects simulated this result and additionally showed cumulative interference over naming cycles. Together with other findings from our research group and in the literature, these results suggest that co-activation from a variety of sources can drive interference.

**Keywords:** semantic interference; form preparation; word production; cyclic naming; incremental learning

## Semantic Persistence and Interference

Long term enhancement (priming) of conceptual-lexical linkages occurs through incremental learning when words liaise with meanings. This occurs in a variety of tasks, including semantic decision tasks (Becker, Moscovitch, Behrmann & Joordens, 1997) and category-exemplar generation tasks (e.g., Blaxton & Neely, 1983), and leads to enhanced accessibility of the bolstered items at a later time. The phenomena of retrieval-induced forgetting and semantic inhibition (e.g., Levy & Anderson, 2002; Blaxton & Neely, 1983) are arguably reciprocal manifestations of this process. In these cases, items related to targets suffer reduced accessibility (interference). Recent work in word production supports the hypothesis that lexical-conceptual priming and interference are indeed complementary. Generation of names from pictures or definitions leads not only to enhanced accessibility of spoken names, but also to simultaneous reduction in accessibility of co-activated unspoken ones (e.g., Belke, Meyer & Damian, 2005; Belke, 2013; Damian & Als, 2005; Wheeldon & Monsell, 1994). Computational models have shown that priming and interference may indeed be 'two sides of the same coin' (Oppenheim, Dell & Schwartz, 2010; see also Howard, Nickels, Coltheart & Cole-Virtue, 2006).

In this article, we focus on the balance between priming and interference in the context of the blocked cyclic naming task. In blocked cyclic naming, participants cyclically name small sets of pictures that typically share a semantic property (related condition) or do not (unrelated condition). Naming is typically slower in the related condition suggesting that interference outweighs priming in this task. In the computational model of Oppenheim et al., conceptual-lexical weights are incrementally strengthened for selected items but weakened for unselected ones, and these adjustments are proportionate to the distances of items from their desired states. Thus if a selected name was less activated than it should be it will be more accessible next time it is needed, but if an unselected competitor word is more activated than it should be it will be less accessible. Importantly, over time, the benefit to selected targets will diminish asymptotically, but the cost to over-activated competitors is chronic. In blocked cyclic naming, items take turns as targets and competitors, and so over naming cycles interference outweighs priming.

Whereas semantic interference has usually been studied in taxonomic domains such as basic categories, Abdel Rahman and Melinger (2011) have shown that it also applies to *ad hoc* situations. For example, the ostensibly unrelated items *stool, knife, bucket, river* can be linked by the contextual theme *fishing trip.* Crucially, interference arose only when participants were informed of the unifying theme. This raises a question about the nature of semantic interference: Why should interference arise equally for intrinsically related taxonomic category members and for *ad hoc* ones? Recently, O'Séaghdha et al. (2013) proposed that whereas facilitatory priming of targets naturally applies to currently activated meanings, interference suffered by relevant competitors may be an oblivious process that is indifferent to the source of the competitor activation. This *mere co-activation* hypothesis was motivated by the evidence of *ad hoc* contextual interference as well as convergent evidence from several other studies by our research group. Packer, O'Séaghdha, Hupbach & Bates (2013) found interference in naming faces of unknown individuals linked only by being part of an identifiable ethnic/racial category. This suggests that it is not necessary to know anything specific about the depicted individuals for interference to occur. All that is required seems to be that the names be grouped. In another study, Preusse and O'Séaghdha (2014) tested remote associate test (RAT) items in blocked cyclic naming during problem solution. For example, the solution for the pictures Axe, Syrup, and Bird was TREE. We found that merely searching for a hidden relation between items during picture naming induced strong interference for actual RAT sets before they were solved, and also for false RATs that had no solution.

In this article, we focus on another line of convergent evidence, blocked cyclic naming of pictures whose names are related in both meaning and form (see Table 1). Following the co-activation hypothesis, we predicted that augmenting activation of semantic competitors with a nonsemantic property (shared first phoneme) would increase semantic interference. This is a strong prediction because sharing form alone leads to facilitation (Meyer, 1991) from an extra-lexical attentional process (O'Séaghdha & Frazer, 2014; see Figure 1). If facilitatory form preparation occurs in combined semantic-phonological sets, semantic interference will be underestimated.

## Experiment: Combined Semantic and Phonological Activation

We conducted a blocked cyclic naming experiment to test the separate and combined effects of semantic and phonological similarity. In the semantic condition, items were taxonomically related. In the phonological condition, they shared the first phoneme. In the combined condition, they shared both taxonomic category and first phoneme. The key prediction is increased semantic interference in the combined condition. In order to estimate phonological preparation, we tested the phonological similarity condition separately as well as within the main experiment.

### Method

**Participants** Twenty-one native English speaking undergraduate students at Lehigh University participated to fulfill a course requirement.

**Design** Three Set-Types (Semantic, Phonological, Combined) were tested in two Contexts (Related, Unrelated) within subjects. In addition, 3 Versions of the experiment, in which different items were rotated between the Combined and other conditions (see Materials for details), were administered to different subsets of participants. Version was included as a factor in analyses, but is not theoretically relevant, and so will not be discussed further.

**Materials** Three items beginning with a constant phoneme were selected for the categories vegetables (/k/), birds (/p/), and flowers (/l/) to create the Combined sets. These items when viewed horizontally comprised Combined unrelated sets (see Table 1a). Two more items from each category were selected for the Semantic sets in such a way that they also met the requirements for formation of Phonological sets. The Semantic and Phonological sets were completed by items that were also used in the Combined conditions (see Table 1b). Three counterbalanced versions of the materials rotated different items from the Combined conditions into the Semantic and Phonological conditions in order to make a within items analysis possible. Version 1 is shown in Table 1b. In practice, this elaborate counterbalancing was ignored in the analysis because the data proved to be too sparse, and so we report only aggregate data collapsed over versions here. Note that the unrelated sets for the Combined conditions are simply crossed with the related (see Table 1a). The unrelated controls for the Semantic and Phonological conditions (color coded) were sets that shared neither category nor first phoneme. These sets were exactly the same for both conditions. To keep the ratio of related to unrelated sets at 50:50 these unrelated sets were presented twice, and they were randomly assigned as semantic or phonological controls.

All items were easily picturable disyllabic nouns. Pictures were obtained from a free online stock photo website Stock.XCHNG (www.sxc.hu) or were created by a lab member if a suitable photo was not located. Images were cropped when needed and resized to 500 x 500 pixels using MS Paint, then saved as .jpg files for use with E-Prime 2.

**Procedure: Blocked Cyclic Naming** The experimenter explained that the task was to repeatedly name small sets of pictures as quickly and accurately as possible. Before the testing phase, participants were familiarized with all 18 pictures and corresponding names. In order to familiarize them with the testing procedure, participants also completed one related and one unrelated phonological practice set with items that were not used in the experiment.

**Figure 1:** A simplified diagram of activation and incremental learning during blocked cyclic picture naming in the combined condition. BIRD and OCEAN activate *puffin* and BIRD also partially activates *pigeon* and *peacock*. Links between conceptual features and *puffin* are strengthened, whereas links from BIRD to competitors (*pigeon* and *peacock*) are weakened in proportion to their activation. Sharing the first phoneme causes additional activation of the words and more incremental interference.

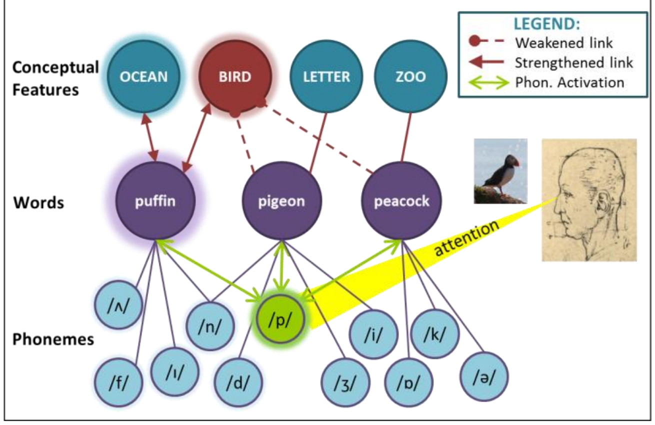


**Table 1a**. The pictures used in the Combined (Semantic and Phonological) sets with their unrelated controls. The items in unrelated set 3 were rotated through the Semantic and Phonological conditions in the version shown in b.

**1b.** One of three versions for the Semantic and Phonological conditions. Six items were constant in all semantic and phonological versions. Unrelated control sets (e.g., *parsnip*, *condor*, *lilac*) are color coded.

| **a.** | | **Related Combined Sets** | | |
|---|---|---|---|---|
| **Unrelated Combined Controls** | | Vegetables /k/ | Birds /p/ | Flowers /l/ |
| | 1 | collards  | puffin  | lily  |
| | 2 | carrot  | pigeon  | laurel  |
| | 3 | *cabbage*  | *peacock*  | *lilac*  |

| **b.** | | **Related Semantic Sets** | | |
|---|---|---|---|---|
| **Related Phonological Sets** | | Vegetables | Birds | Flowers |
| | /p/ | parsnip  | *peacock*  | poppy  |
| | /l/ | lettuce  | lapwing  | *lilac*  |
| | /k/ | *cabbage*  | condor  | crocus  |

For testing, participants were first shown a set of three pictures. Each picture was displayed vertically on the screen with the corresponding names on the right. Participants named the three pictures aloud once. Then they entered the cyclic naming phase, naming the pictures as quickly and accurately as possible as they appeared sequentially in seven cycles. The order was random except that the same picture could never appear consecutively. For each trial, a fixation point appeared in the center of the screen for 100 ms. This was followed by a 250 ms blank screen accompanied by a warning tone. Then the picture appeared in the center of the screen for up to 1150 ms or until a response was detected by the voice key. Following the response, a blank interval of 1500 ms preceded the next picture. If no response was detected, the message “Too slow” appeared for 500 ms accompanied by a 250 ms warning tone and followed by a 1000 ms blank screen prior to the next picture. Each of the three pictures was named once in a random order in each of 7 naming cycles. Eighteen sets were presented in a random order. Following presentation of all sets, the entire procedure was repeated in a second block. The second block data were not informative and so only the first block data are reported here.

**Phonological pretest** To provide a baseline for the effect of phonological onset sharing we tested the phonological condition alone on a separate set of 17 participants. The procedure was exactly the same as in the main experiment, but used only the phonological sets and controls.

## Results

**Data Scoring** Errors were classified as productions where the participant did not produce the correct target or produced the target word incorrectly (2.57% word production errors), did not speak loudly enough for the voice key to detect a response, did not produce a response in the allotted amount of time, where the voice key was tripped by other environmental noise, or where the initiation time was unrealistically short (< 150ms) (4.06% for these non-linguistic errors). Thus, in total 6.63% of the data were removed due to error.

Because items could not repeat, the third item in a cycle was always determinate. Inspection of the data showed that participants were remarkably good at tracking the cycles, and predicted every third item in the tests with high reliability, thus desensitizing those trials to the manipulations. Therefore we also eliminated the last response in every cycle from the analyzed data. Note that because items could not repeat, except for the very first response, the probability of either of the first two pictures within a cycle was .5.

As predicted, semantic interference was almost doubled in the combined semantic-phonological condition (- 40 ms) compared to the semantic-only condition (- 23 ms) (see Figure 2). Surprisingly, there was no facilitation in the phonological condition, but instead a slightly negative outcome (- 6 ms).

**Phonological Condition** Detailed examination of the phonological condition data suggested that the absence of facilitation could be due to several considerations. First there may have been ‘bleeding’ of interference from the semantic and combined conditions. For example, items that rotated through the combined condition as well as semantic and phonological conditions showed substantial interference (- 16 ms) whereas items that appeared only in phonological and semantic conditions did not (+ 1 ms). Second, task demands may have limited phonological preparation. According to O’Séaghdha and Frazer’s (2014) attentional account of form preparation, attention to other aspects of the experiment such as previous appearances of words in different contexts could occupy attention and thus displace the limited capacity available for phonological preparation. In contrast, when the phonological items were tested separately in the pre-test, they showed a robust facilitation effect (+ 18 ms, see Figure 2). This effect was significant, F (1, 14), = 5.69, p = .03. Thus, phonological conditions tested alone showed a standard form preparation benefit (Meyer, 1991; O'Séaghdha & Frazer, 2014), but this was not the case when these conditions were intermixed with others in the main experiment. Because there was no phonological facilitation in the main experiment, we now focus on the semantic and combined conditions.

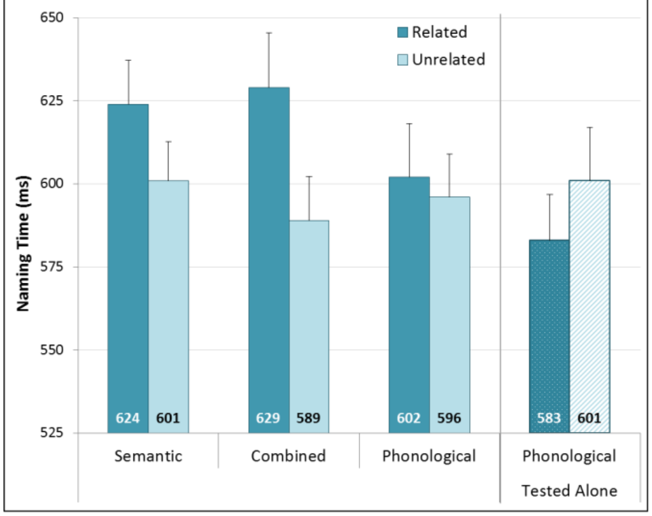
**Semantic and Combined Conditions** The key prediction was greater interference in the combined than in the semantic condition. To test this, we conducted a Repeated Measures ANOVA on these conditions with Set-Type (Semantic, Combined) and Context (Related, Unrelated) as the variables of interest. We found a robust context effect, F (1, 18) = 21.98, p < .001. In addition, the modulation of the context effect by condition was marginally significant, [Set-Type x Context interaction, F (1, 18) = 3.95, p =.06].

**Cycles** Figure 3a shows the effects in the Combined and Semantic conditions with their condition-specific baseline controls broken out over the 7 naming cycles. Although the data are somewhat noisy, it can be seen that the separation of the related and unrelated data is consistent over cycles in both conditions, and the separation is larger in the Combined condition. However, there is no clear overall acceleration of naming times in the baseline conditions, and the interference effects do not increase systematically over cycles. These outcomes can be understood as resulting from the extensive recycling of items through multiple conditions in the experiment. In effect, unrelated items show interference from their exposure to related conditions, and increased interference over cycles may affect both the related and unrelated conditions. This equilibration of related and unrelated responses can be avoided by using different items and balancing them across participants (see Preusse & O'Séaghdha, 2014).

## Computational Model

Whereas our experiment confirms the key prediction of heightened competition in the combined semantic-phonological condition, there are some ambiguities. First, phonological preparation may be absent or may be overwritten by semantic interference. Second, there is evidence of such cross-condition influences, especially for items that served in multiple conditions in semantic and combined as well as phonological conditions. Third, the flatness of the cycle data (Figure 3a) suggests that carry-over effects apply to unrelated baseline conditions. In addition to providing insight into the underlying mechanisms of semantic priming and interference (Oppenheim et al., 2010), computational models can isolate these processes. Therefore we implemented an extension of the Oppenheim et al. model with the following goals:

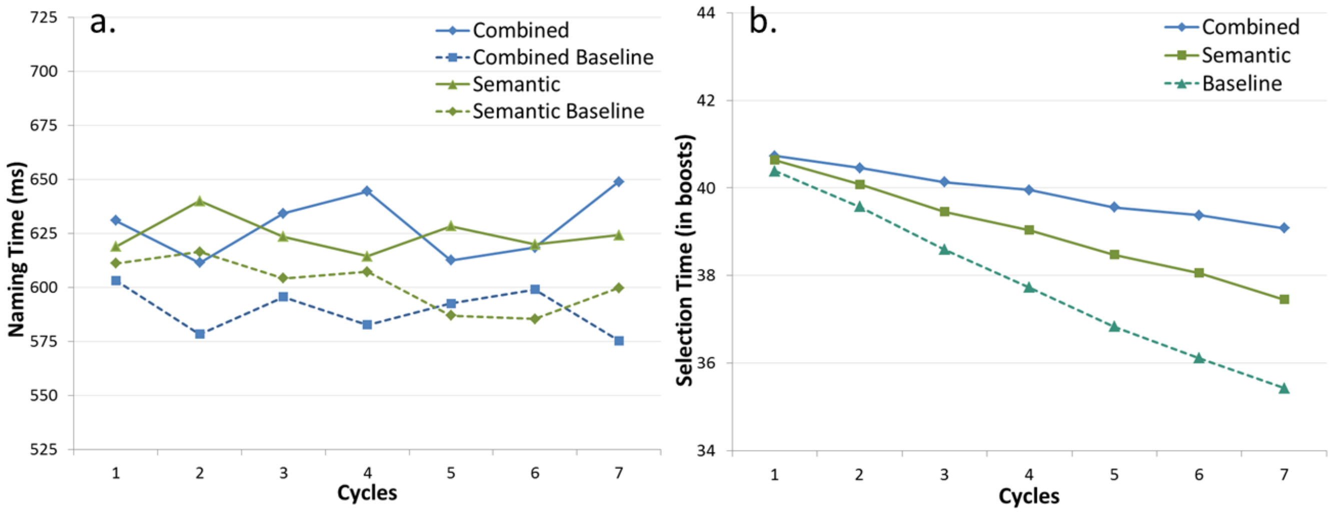
**Figure 2.** Mean naming times with standard errors in Semantic, Combined, and Phonological conditions with Unrelated controls, and in a separate pretest of the Phonological condition alone.




1. Isolate the incremental learning process
2. Introduce a combined semantic-phonological condition
3. Eliminate third-item anticipation strategies as well as possible phonological preparation processes
4. Eliminate carryover effects between related and unrelated conditions

The model is a simple two-layer network that maps conceptual feature inputs to word outputs (see Figure 1). The network has 6 features that connect to a mini-lexicon of 9 words. Each word has just two features. The network was first trained on the whole vocabulary so that each word was linked to its features. As in Oppenheim et al., noise (.5) was added throughout learning. Ten thousand training runs, each comprising 100 passes through the vocabulary, were averaged to provide a stable trained state. Learning was implemented by a standard delta rule (see Oppenheim et al., 2010, for details). For testing, we emulated the conditions of the naming experiment as closely as possible by using sets of three words. In the related semantic condition, the words shared one feature and had one other non-shared feature. In the combined (semantic and phonological) condition, phonological relatedness was implemented by providing an additional component of activation (value = .035) that was not deployed during training. Total activation was never greater than 1. Conceptually, this additional activation corresponds to the phonological-attentional process diagrammed in Figure 1. This activates the shared word beginning and thus heightens the activation of the words in a combined semantic-phonological set. In the heterogeneous control condition, there were no shared features. Importantly, each condition was tested independently from the same starting point in the trained network, and so there could not be any carryover effects.

**Figure 3** **a.** Mean Naming Time for Combined and Semantic Conditions in the Experiment over 7 Naming Cycles. **b.** Corresponding Selection Time Data from the Model.




Following Oppenheim et al. (2010), word name selection was simulated using a booster mechanism that iteratively augmented activation of target and competitor words until there was sufficient separation between them (i.e., activation of one of the words passed a differential threshold). Thus, the more competition a target experienced, the longer it took to select it. Following target selection, the connection weights were updated using the same learning rule as in training. These changes were based on the initial activations of items prior to boosting and so are independent of the decision process. They thus reflect modulation of the network by the concentrated experience of cyclic naming of small sets of words in the three conditions, but they are not influenced by the transient challenges of selection. That is, incremental learning influences selection but not vice versa.

Figure 3b shows the results of the model simulations. In comparison to the corresponding experimental data the simulation has several distinct outcomes. First there is clear learning in all conditions, contrasting with the flatness of the human data. Second the interference effects are cumulative, increasing systematically over testing cycles. Similar to the human data, the model shows greater interference in the combined than in the semantic condition. Thus, the model was successful in isolating the incremental learning process and thus supports its plausibility.

## Discussion

The key finding of this study is that interference was increased when items were both phonologically and semantically similar compared to when they were only semantically related. We observed clear semantic interference in the Semantic condition (- 23 ms) and substantially more in the Combined (semantic and phonological) condition (- 40 ms). Though clearly consistent with our prediction, the difference in interference in the two conditions is statistically marginal ($p = .06$). For this reason, the incremental learning model simulation is especially important.

The model showed that to the extent that sharing of phonological onsets increases activation of targets and competitors it necessarily increases interference that is leveraged through the implemented incremental learning mechanism. Such a mechanism is a widely endorsed explanation of interference in cyclic naming and related paradigms (e.g., Navarrete, Del Prato & Mahon, 2012). At the same time, its implementation in the model must be interpreted with caution. The separation between the semantic and combined conditions (see Figure 3b) is a direct function of the weight assigned to the phonological input parameter in the simulation. New empirical work that more closely matches the model in segregating the various conditions is required to determine the actual weight that should be assigned to shared phonological word beginnings.

In addition to comparing semantic and combined conditions, we examined a phonology-only condition in the experiments. Here, following the extensive form preparation literature, we observed facilitation rather than interference when the phonology conditions were tested alone. In contrast, the data tended to interference when the same conditions were tested within the main experiment. This may have been a result of carryover effects from the semantic and combined conditions. The nine phonological items were always shared with the semantic conditions and they included three items that also featured in combined conditions. In addition, participants may have withheld form preparation under these conditions (O'Séaghdha & Frazer, 2014).

Our simulation did not include the phonological condition because merely activating items through phonology would have no effect on incremental learning. This is because the model as configured only adjusts links that are conceptually active, but it raises a question about the generality of this implementation. Our study, in combination with related findings, points to the need to further elaborate and refine accounts of semantic interference. In particular, these accounts need a way to capture thematic or goal-driven semantic relevance as well as taxonomic similarity (see earlier discussion of Abdel Rahman & Melinger (2011) and Preusse & O'Séaghdha (2014)). A challenge for future models is to distinguish mere activation of words from activations that warrant conceptual-lexical adjustment. Here our findings provide a useful pointer. Picture naming is often characterized as an excellent production task that captures conceptual-lexical as well as phonological processes, but we did not observe significant interference in the phonological conditions. Moreover, brain imaging evidence confirms that selection difficulty in cyclic naming arises in semantic but not in phonological conditions (Schnur et al., 2009). Our findings suggest that incremental learning of conceptual-lexical links responds to semantic but not to phonological similarity, but cannot discriminate the sources of combined semantic-phonological activation.

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