

Looking for meaning: Eye movements are sensitive to overlapping semantic features, not association

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Theories of semantic memory differ in the extent to which relationships among concepts are captured via associative or via semantic relatedness. We examined the contributions of these two factors, using a *visual world paradigm* in which participants selected the named object from a four-picture display. We controlled for semantic relatedness while manipulating associative strength by using the visual world paradigm's analogue to presenting asymmetrically associated pairs in either their *forward* or *backward* associative direction (e.g., *ham–eggs* vs. *eggs–ham*). Semantically related objects were preferentially fixated regardless of the direction of presentation (and the effect size was unchanged by presentation direction). However, when pairs were associated but not semantically related (e.g., *iceberg–lettuce*), associated objects were not preferentially fixated in either direction. These findings lend support to theories in which semantic memory is organized according to semantic relatedness (e.g., distributed models) and suggest that association by itself has little effect on this organization.

Models of semantic memory differ in how relationships among concepts are captured. Associative relations play an important role in spreading activation models (e.g., Anderson, 1983; Collins & Loftus, 1975), whereas in distributed models, semantic feature overlap is critical (e.g., Masson, 1995). However, both types of model assume that when a concept is activated, related concepts also become partially active. The paradigm most commonly applied to testing these models is semantic priming. Two recent reviews of this literature (Hutchison, 2003; Lucas, 2000) concluded that automatic semantic priming does not *require* association. Although this conclusion is consistent with distributed models, both reviews also showed some role for association, suggesting that it too plays a role in the organization of semantic memory.

Using semantic priming to test associative versus semantic relations can be problematic, however. Because the prime and target are typically paired, participants may notice relationships and engage in strategies to perform the task (Neely, Keefe, & Ross, 1989), limiting the conclusions that can be drawn about the organization of semantic memory. It is therefore necessary to take great methodological care to ensure that semantic priming is not due to controlled processing—especially when testing associative relations, since they tend to be more obvious during semantic priming.

Evaluating the role of association is further complicated by the fact that most associated concepts are also semantically related. In the priming literature, the strength of *association* between a pair of concepts describes the probability that one will call the other to mind, and although this variable reflects a variety of relationships (e.g., antonyms, synonyms, words that co-occur in language, category co-

ordinates, etc.), most of these are semantic. Furthermore, concepts that are strongly semantically related are usually strongly associatively related as well, making it difficult to test either associative or semantic relatedness in isolation. One way to circumvent this problem is to take advantage of a key difference between associative and semantic relationships: As typically defined, association can be asymmetrical, but semantic relations cannot. For example, *ham* and *eggs* are asymmetrically associated because, although the cue *ham* frequently elicits the response *eggs*, the cue *eggs* does not often elicit *ham*. At the same time, because *ham* and *eggs* share the same number of semantic features regardless of which concept is first activated, their semantic relationship is symmetrical.

In an exploration of the effects of semantic and associative relatedness on automatic semantic priming, Thompson-Schill, Kurtz, and Gabrieli (1998; henceforth TKG) exploited the asymmetry of association strength. They used asymmetrically associated pairs that were either semantically related (e.g., *sleet–snow*) or semantically unrelated (e.g., *lip–stick*) and presented them in both the forward (e.g., *lip–stick*) and backward (e.g., *stick–lip*) directions. In this way, they varied association strength within a pair while keeping the semantic relationship constant.¹ Associative theories predict that backward priming should be weaker than forward priming because activation should spread only in the direction of association. They also predict that associated pairs should exhibit priming in the absence of semantic relatedness. Distributed theories, on the other hand (unless supplemented with associative links; e.g., Plaut, 1995), predict equal priming in both directions and no priming for pairs that are semantically unrelated, regardless of their association.

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TKG's findings were consistent with distributed theories. Priming was equal in the forward and backward directions for semantically related pairs. Furthermore, they observed no priming for semantically unrelated pairs (in either direction). These findings suggest that association alone plays little, if any, role in semantic memory. This conclusion contrasts with demonstrations that semantically related pairs that are unassociated produce less priming than do those that are semantically related and associated (see Lucas, 2000, for a review). Two possible reasons for this discrepancy are that controlled processing played a role in the prior studies and that pairs that are semantically related and associated are generally more strongly semantically related than are those that are not associated (see McRae & Boisvert, 1998). Another possibility has been raised, however: Despite TKG's efforts to control for association strength, their semantically unrelated pairs were not as strongly associated as their semantically related pairs (according to the University of South Florida [USF] free association norms; Nelson, McEvoy, & Schreiber, 1998). It therefore remains possible that the lack of priming in TKG's semantically unrelated condition was due to weaker association (Hutchison, 2003).

In the present study, we test the predictions of associative versus distributed models of semantic memory, using stimuli that are better controlled than TKG's. We also avoid some of the problems with semantic priming by using a new paradigm. A new paradigm is desirable because standard semantic priming tasks (lexical decision and naming) make minimal demands on semantic processing, meaning that weaker relationships may not be detected. Furthermore, the manipulation typically used to prevent controlled processing—a short stimulus onset asynchrony (SOA)—limits the paradigm's ability to detect relationships that may become active slowly; perhaps nonsemantic associative relationships have failed to emerge under these conditions (Shelton & Martin, 1992; TKG) because associative relations emerge more slowly than semantic ones.

In a standard *visual world* eyetracking paradigm, participants are presented with a multipicture display and are asked to click on one of the objects (the target). If one of the objects is semantically related to the target word, participants are more likely to fixate on this related object than on unrelated objects (e.g., Huettig & Altmann, 2005; Yee & Sedivy, 2006). For example, when instructed to click on a candle, one is more likely to fixate on a picture of a lightbulb than on unrelated objects. This *relatedness effect* appears to be the result of a match between the semantic attributes of the related object and the conceptual representation of the activated target word (cf. Altmann & Kamide, 2007).

The visual world paradigm can provide useful insight into semantic versus associative relationships because the related object is one of three distractor objects and is never singled out. Hence, participants are unlikely to notice the relationship between objects in the display, and unlikely to engage in controlled processing. Furthermore, mapping a spoken word onto a picture places demands on seman-

tic processing that are not required in word pronunciation and lexical decision. Finally, because eye movements are sampled continuously over a long window, we are not limited to probing at a single SOA and, hence, may be able to detect effects that occur at different times.

METHOD

Participants

Thirty male and female undergraduates from the University of Pennsylvania received course credit for participating. All were native speakers of English and had normal or corrected-to-normal vision and no reported hearing deficits.

Apparatus

An EyeLink II head-mounted eyetracker monitored participants' eye movements. Stimuli were presented with PsyScript (Bates & D'Oliveiro, 2003).

Materials

Using the USF free association norms, we selected stimulus pairs that were more strongly associated in one direction than in the other. To assess semantic relatedness, a separate set of 30 participants rated pairs of clip art images (from Rossion & Pourtois, 2004, or a commercial collection) from 1 to 7 on "how similar are these things." Pairs rated lower than 3 were assigned to the *nonsemantic* condition ($M = 1.6$; e.g., *iceberg-lettuce*); pairs rated higher than 3 were assigned to the *semantic* condition ($M = 4.2$, e.g., *ham-eggs*). Mean forward and backward association strength was equivalent across the two conditions (nonsemantic, forward = .15, backward = .00; semantic, forward = .15, backward = .01).

In the nonsemantic condition (22 trials), the target² was associatively but not semantically related to one of the other three objects in the display (Figure 1, left panel). Related pairs appeared in both their *forward* and *backward* associative directions. The target in the forward direction (e.g., *iceberg*) was the word that commonly elicited the associate. The target in the backward direction (e.g., *lettuce*) infrequently elicited the associate. The other two objects in the display were semantically, associatively, and phonologically unrelated to the related pair. One unrelated object's name was frequency matched with that of the target, and the other with that of the related object. The design of the semantic condition (24 trials) was analogous, except that the pairs were semantically as well as associatively related (Figure 1, right panel). These pairs also appeared in their *forward* (e.g., target: *ham*) and *backward* (e.g., target: *eggs*) associative directions.

Two lists, each 179 trials, were created. All pairs (nonsemantic and semantic) appeared on each list, but half were presented in the forward direction, and half in the backward direction (counterbalanced between lists, so that no participant saw any object more than once). Each list also included 16 *semantic distractor* trials, on which two of the objects in the display were related to each other but not to the target. Therefore, the presence of a related pair could not be used to predict the target. There were 117 filler trials, on which no objects in the display were related. Target words were recorded by a female speaker (E.Y.) in a quiet room.

To determine whether visual similarity was comparable across conditions, an independent group of 24 participants provided visual similarity ratings (from 1 to 7) for all related and control pairs (i.e., similarity between the object referred to by the target word and the image of the related or word-frequency-matched unrelated object). In the nonsemantic condition, visual similarity ratings did not differ between target-related and target-control pairs (forward = 1.5, forward control = 1.2, backward = 1.4, backward control = 1.4). In the semantic condition, however, ratings were higher for target-related than for target-control pairs (forward = 2.1, forward control = 1.4, backward = 2.4, backward control = 1.4). (Since

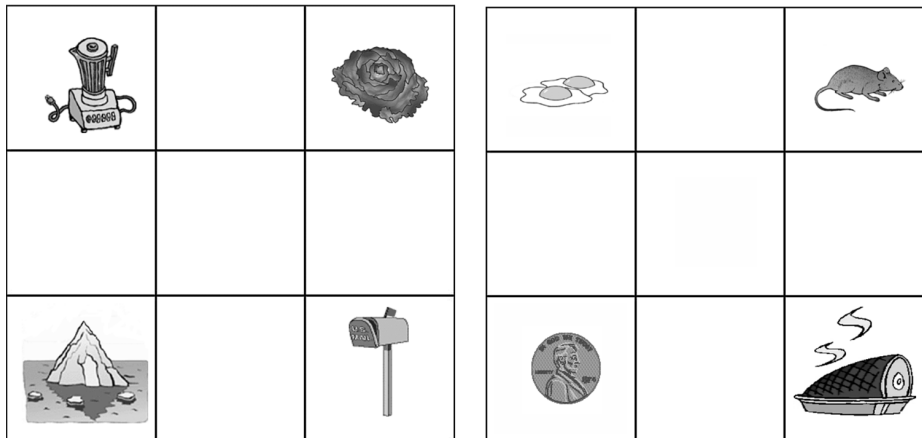


Figure 1. Sample displays from the nonsemantic (left panel) and semantic (right panel) conditions. In the nonsemantic condition, the participant hears a target word (e.g., *iceberg*) that is associatively but not semantically related to one of the other objects in the display (e.g., the lettuce). In the semantic condition, the target word (e.g., *ham*) is associatively and semantically related to one of the other objects in the display (e.g., the eggs). The other two objects are unrelated to the target or the related object. Each display is used in both the forward and the backward direction (between participants).

semantically related objects often have similar shapes, this difference is expected.) We therefore used these visual similarity ratings as covariates in analyzing the eyetracking data.

Procedure

Picture exposure. To ensure that the participants knew what the pictures were supposed to represent, they viewed each picture and its label immediately before the eyetracking experiment.

Eyetracking. The participants were seated approximately 18 in. from a touch-sensitive monitor. They were presented with a 3×3 array (each cell was 2×2 in) with four pictures, one in each corner (Figure 1). Two seconds after the display appeared, a sound file named an object in the display. After the participant selected a picture by touching it, the trial ended, and the screen went blank. There were two practice trials.

Eye movements were recorded, starting from when the array appeared and ending when the participant touched the screen. Only fixations initiated after the onset of the target word were included in our analyses. We defined four regions, each corresponding to a corner cell in the array. We defined a fixation as starting with the beginning of the saccade that moved into a region and ending with the beginning of the saccade that exited that region.

RESULTS AND DISCUSSION

Across all participants, seven trials (0.5%) were excluded because the wrong picture was selected. Nine percent of the trials did not provide any data, because there were no eye movements after target word onset (in most of these, the participant was already fixating the target picture at word onset). For the remaining data, we computed the proportions (across trials) of fixations on each picture type (target, related, control) over time in 100-msec bins (see Figures 2 and 3). For each bin in each condition, fixation proportions more than 2.5 standard deviations from the mean were replaced with the mean for that bin in that condition.

For data analysis, we defined a trial as starting 200 msec after target onset (approximately 180 msec is needed to

initiate a saccade to a target in a task like this; Altmann & Kamide, 2004) and ending 1,100 msec after target onset, the average time that the probability of fixating on the target reached asymptote. We binned data into nine bins (from 200 to 1,100 msec after target onset) and submitted these bins to an ANOVA, with condition (related or unrelated) and time as repeated measures.³ In the item analyses, picture-based visual similarity ratings were included as a covariate.

In the nonsemantic condition (Figure 2), there were no effects of relatedness in either the forward [$F_1(1,29) = 1.1, p = .31$; $F_2(1,20) = 0.8, p = .38$] or the backward [$F_1(1,29) = 1.4, p = .25$; $F_2(1,20) = 0.3, p = .61$] direction. In neither direction was there an interaction of relatedness with time. In the semantic condition (Figure 3), in contrast, there was a significant effect of relatedness in both the forward [$F_1(1,29) = 9.7, p < .01$; $F_2(1,22) = 4.9, p = .04$] and the backward [$F_1(1,29) = 15.7, p < .001$; $F_2(1,22) = 4.4, p = .05$] directions. Because picture-based visual similarity was covaried out in the items analysis, this effect cannot be attributed to visual similarity. In both directions there was an interaction of relatedness with time that was significant by participants [forward, $F_1(8,29) = 3.4, p = .01$; backward, $F_1(8,29) = 2.8, p = .01$], but not by items [forward, $F_2(8,22) = 1.9, p = .12$; backward, $F_2(8,22) = 0.8, p = .54$].⁴ The interaction was due to the fact that the relatedness effect did not emerge until after the first few time bins.

To address the critical question of whether direction of association influenced the size of the relatedness effect, we computed the average relatedness effect (fixations on related – control averaged across the entire trial) for each condition. In neither condition was there a difference between the forward and backward directions [$F_1(1,29) = 2.3, p = .14$; $F_2(1,20) = 1.1, p = .31$, and $F_1(1,29) = 0.43, p = .52$; $F_2(1,22) = 0.4, p = .53$, for the nonseman-

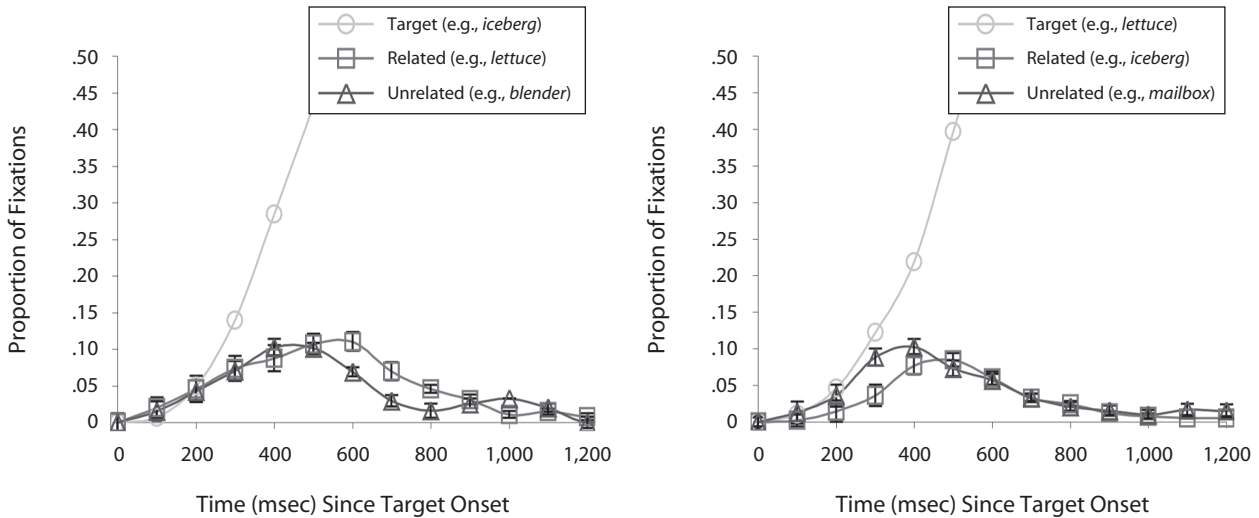


Figure 2. Mean proportions of trials across time containing a fixation on the target, related object, and control object in the forward (left panel) and backward (right panel) directions in the nonsemantic condition. Error bars represent standard errors.

tic and semantic conditions, respectively]. To test whether direction of presentation might have an influence for the most strongly associated pairs, we analyzed the 10 most strongly associated pairs in each condition (nonsemantic, forward = .25, backward = .00; semantic, forward = .25, backward = .01). The effects were unchanged.

A posttest questionnaire indicated that most participants (22 of 30) did not notice any relationships between the objects in the displays. Removing the 8 participants who reported noticing some relationships did not change the pattern of results. To further test for controlled processing, we examined responses on the first 25% of the trials (since strategies would presumably require time to develop). The pattern in these trials was the same as that in the later trials.

Why did we observe no relatedness effect for the nonsemantic pairs in their forward-associative direction?

One possibility is that these relations are weakly (if at all) encoded in semantic memory and, instead, are encoded lexically. If so, association effects in priming studies may occur because priming tasks typically emphasize lexical processing. The eyetracking task, in contrast, emphasizes semantic processing—a feature that makes it more suitable for probing semantic memory. Another possibility, however, is that pictorial depictions bias the focus of attention to some aspects or features of the concept at the expense of others that might be more relevant for a given association. Due to constraints on stimulus selection (which we will return to below), both of these differences would be particularly relevant for the nonsemantic condition.

To test whether, under conditions that increased demands on lexical processing, the pictures used in the eyetracking study would elicit nonsemantic associative priming, 23 separate participants completed a picture-naming

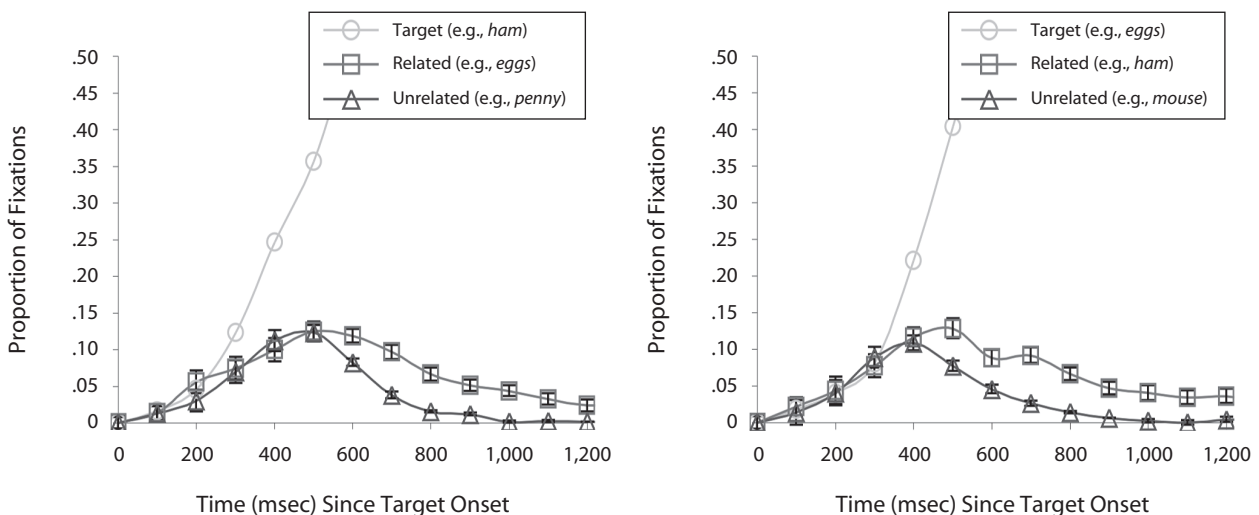


Figure 3. Mean proportions of trials across time containing a fixation on the target, related object, and control object in the forward (left panel) and backward (right panel) directions in the semantic condition. Error bars represent standard errors.

task with these stimuli. After an exposure phase (see the Eyetracking section), the participants were presented with a sequence of individual pictures to name. Pictures were preceded by either a related picture (e.g., *lettuce* preceded by *iceberg*, or vice versa, between subjects) or an unrelated picture (overall frequency and word length matched). Two lists were created so that no picture appeared twice. Response times were measured from the onset of the image to the onset of the name, recorded by a voice key. In the backward direction, there was no priming in either the nonsemantic or the semantic condition. In the forward direction, the priming effect in the nonsemantic condition was significant [$t(21) = 1.8, p = .04$], and the effect in the semantic condition approached significance [$t(22) = 1.7, p = .07$]. Hence, when demands on lexical processing are increased (by requiring participants to produce each picture's name), the pictures used in the eyetracking study produce nonsemantic associative priming. This suggests that the absence of nonsemantic associative priming in the eyetracking study has more to do with the balance of demands on semantic versus lexical processing than with the use of pictures per se.

Our eyetracking findings, which revealed semantic but not associative relatedness effects, converge with those of TKG using an independent paradigm. Because we used the USF norms to match association across our nonsemantic and semantic conditions, this work is not subject to the concern that the null result in the nonsemantic condition could have been due to weaker association for these pairs. The present study also suggests that the absence of nonsemantic, associative priming under automatic conditions in prior studies (Shelton & Martin, 1992; TKG) did not occur because associative relationships are slow to arise and, therefore, undetectable at short SOAs.

The effect that we observed for pairs that were related both semantically and associatively—that is, a significant relatedness effect that, importantly, was unchanged by direction of presentation—is consistent with distributed models. Although it is possible to supplement distributed models with associative links (e.g., Plaut, 1995), the fundamental organizing principle of the distributed semantic architecture is that relatedness is represented via overlapping semantic features. Thus (in the absence of associative supplementation), concepts that are associated but semantically unrelated should not activate each other, but concepts that are associated and semantically related should activate each other equally, regardless of which concept is activated first.

On the other hand, the null result (in both directions) for associatively related but semantically unrelated pairs shows that association alone is not sufficient to produce a relatedness effect, even in a sensitive paradigm such as eyetracking, which allows us to monitor activation over a more extended period of time than do other paradigms. Thus, our results suggest that when semantic processing is emphasized, any automatic conceptual activation of things that are associatively but not semantically related is weak at best. This finding casts doubt on theories of semantic memory that assume an important role for association, because these theories predict that activation should

spread to associated concepts regardless of whether they are semantically related.

It is important to recall, though, that associatively related concepts tend also to be semantically related. One exception is a subset of associated concepts that co-occur in language but are semantically unrelated. Our nonsemantic condition was, therefore, drawn almost exclusively from these co-occurring pairs and primarily comprised the individual components of compound nouns (e.g., *iceberg lettuce*, *ant hill*).⁵ These concepts are nevertheless associated according to norms and, hence, according to associative theories, should activate each other. Because we found no evidence of such activation under automatic conditions, our results suggest that these simple co-occurrence relations play little, if any, role in the organization of semantic memory.

At first glance, the absence of a significant effect of co-occurrence may appear incompatible with a recent study showing that two corpus-based metrics of semantic similarity—latent semantic analysis (LSA; Landauer & Dumais, 1997) and contextual similarity (McDonald, 2000)—can reliably predict relatedness effects in a similar eyetracking paradigm (Huettig, Quinlan, McDonald, & Altmann, 2006). However, because both metrics use distance in high-dimensional space to quantify similarity, they capture much more than simple co-occurrence. In fact, our finding that simple co-occurrence does not lead to a relatedness effect lends support to the possibility (raised by Huettig et al., 2006) that LSA may be a weaker predictor of semantic relatedness effects than is contextual similarity, because LSA relies more heavily on textual co-occurrence.

Although useful for evaluating the role of association in semantic memory, it is important to keep in mind that the co-occurrence relationship represents an unusual case of an associative relationship that is not semantic. This leads to a point raised previously by McRae and Boisvert (1998) and others: Given the heterogeneity of relationships that appear in association norms, associative relations should not be treated uniformly. A deeper understanding of the organization of semantic memory can be achieved by examining the individual semantic relationships that comprise associations.

CONCLUSIONS

The present study indicates that association by itself does not modulate the size of a semantic relatedness effect. This finding is inconsistent with models of semantic memory that posit an important role for associative relations (e.g., spreading activation). The finding is consistent with distributed models of semantics, because these models encode semantic relatedness via overlapping semantic features, and this overlap remains constant regardless of which concept is activated first.

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NOTES

1. TKG also took several steps to ensure that processing was automatic rather than controlled, including using a short SOA and a naming task.

2. In the present study, the *target* refers to the one and only word uttered. This usage differs both from the semantic priming literature, in which the *target* follows the prime and is used to gauge the prime's activation, and from the word association task, in which the *target* is the response to the *cue*.

3. Main effects of time bin were obtained in all analyses. This is unsurprising, because eye movements in early bins reflect the processing of only a small amount of acoustic input, whereas later eye movements converge on the target object. We therefore will limit our discussion to main effects of condition and to condition \times time interactions.

4. It is likely that the interaction with time is not significant by items because of variability in the point at which different words can be identified.

5. Because our nonsemantic associative pairs were primarily compound nouns, the absence of an effect in the forward condition contrasts with prior work showing a relatedness effect for objects semantically related to onset competitors of a heard word (Yee & Sedivy, 2006): The target word in the forward direction (e.g., *iceberg*) could be considered an onset competitor of the compound noun that comprises the target and competitor (e.g., *iceberg lettuce*), which is semantically related to the competitor (e.g., *lettuce*). We suspect that no such onset-mediated semantic effect was obtained in the present study because the compound words that made up the *onset competitors* were of low frequency and, hence, should be only weakly activated.

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