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Lexical Inhibition and Sublexical Facilitation Are Surprisingly Long Lasting

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When a listener hears a word (*beef*), current theories of spoken word recognition posit the activation of both lexical (*beef*) and sublexical (/b/, /i/, /f/) representations. No lexical representation can be settled on for an unfamiliar utterance (*peef*). The authors examined the perception of nonwords (*peef*) as a function of words or nonwords heard 10–20 min earlier. In lexical decision, nonword recognition responses were delayed if a similar word had been heard earlier. In contrast, nonword processing was facilitated by the earlier presentation of a similar nonword (*baff*–**paff**). This pattern was observed for both word-initial (*beef*–**peef**), and word-final (*job*–**jop**) deviation. With the word-in-noise task, real word primes (*beef*) increased real word intrusions for the target nonword (**peef**), but only consonant–vowel (CV) or vowel–consonant (VC) intrusions were increased with similar pseudoword primes (*baff*–**paff**). The results across tasks and experiments support both a lexical neighborhood view of activation and sublexical representations based on chunks larger than individual phonemes (CV or VC sequences).

Keywords: spoken word recognition, perception, sublexical representation, neighborhood, cohort

Given the complexity and variability of spoken language, the ability of a listener to understand a speaker is quite impressive. Over the last half century, researchers have gradually been unraveling the complexities of the system that accomplishes this remarkable feat. Most current theories in this domain assume that the word recognition system relies on both word-level (lexical) representations and some kind of smaller (sublexical) units, such as phonemes or syllables. In such theories, it is necessary to specify both the nature of these representations and the processes involved in relating these representations to the input signal.

In the current study, we address three issues that bear on these central theoretical questions: (a) What is the nature of the competition that occurs among activated lexical entries? Many studies have shown that such competition occurs, but there are at least two different views of this competition. Some models emphasize the dynamic change in the set of competing lexical entries (e.g., the cohort model and models that have incorporated its emphasis on word onsets; Marslen-Wilson, 1987, 1990; Marslen-Wilson, Moss, & Van Halen, 1996); other models define competition in terms of a similarity space that includes all other words that are minimally different regardless of the region of overlap or difference (e.g., the neighborhood activation model; Luce & Pisoni, 1998). (b) What type(s) of sublexical information can be activated by speech input and used to represent and recognize spoken words? The most common sublexical unit that is included in most models is the phoneme (e.g., McClelland & Elman, 1986; Norris, McQueen, & Cutler, 2000), but there is evidence supporting a role for larger units, such as onset and rime (e.g., Treiman, 1985, 1986; Treiman & Kessler, 1995). (c) Is it useful to make a distinction between immediate word recognition versus the longer term representation of the information used in spoken word recognition? There is some evidence from recent work (e.g., Sumner & Samuel, 2005) suggesting that it may be important for theories to distinguish between the apparent behavior of the word recognition system and the underlying representations used to produce that behavior.

In a recent study (Sumner & Samuel, 2005), we obtained an intriguing result that can potentially inform these three areas of research simultaneously: In a long-term priming study, we found that hearing a real word (e.g., *flute*) inhibited a listener's ability to reject a similar pseudoword (e.g., **floose**) that was presented in a separate block 10–20 min later. Lexical decision times to these related pseudowords were significantly slower than to repeated pseudowords or to completely new pseudowords. This inhibitory effect suggests that a change in activation or representation of the word heard in the first block was interfering with a listener's ability to say "no" to a similar pseudoword.

Perhaps unsurprisingly, there has been relatively little research on recognition of spoken nonwords, as opposed to spoken words. In fact, we did not even discuss this nonword inhibition effect in Sumner and Samuel (2005) because it was in a control condition that was tangential to the focus of that article on word recognition as a function of phonological variation (specifically, the three phonological variants of /t/ in final position). Despite the natural bias toward studying real words, there are a number of benefits to

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examining pseudowords. If the inhibitory effect that we found is in fact robust, it can be used to constrain models of lexical and sublexical representation and activation. For example, we can use this effect to directly contrast predictions made by the cohort (e.g., Marslen-Wilson, 1987, 1990; Marslen-Wilson et al., 1996) versus the neighborhood activation model (e.g., Luce & Pisoni, 1998). Because the inhibitory effect was found for word–pseudoword pairs that differed in final position (e.g., *flute*–**floose**), both model types can account for the competition. But, by moving the deviation to the initial position (e.g., *beef*–**peef**), the two model types diverge in their predictions. A cohort model of activation should predict that hearing a word such as *beef* early on would have no effect on the later processing of the pseudoword **peef**, because the two are not competitors. A neighborhood model, on the other hand, should predict an inhibitory effect regardless of the position of deviation.

As we have noted, our initial result came from an experiment that was testing an entirely different hypothesis. Therefore, in the current study, we report a comprehensive set of experiments, using two very different versions of a long-term priming paradigm, designed to both demonstrate the strength of the initial effect and use this effect to explore the three theoretical issues discussed above. In Experiments 1 and 3, we examine targets that deviate finally from their primes (e.g., *job*–**jop**), and in Experiments 2 and 4, we examine targets that deviate initially from their primes (e.g., *beef*–**peef**).

The results of our long-term priming tasks can be compared with research examining the immediate form priming of similar pairs. Researchers examining these immediate effects have found a consistent asymmetry for the two cases, with inhibition for finally deviant pairs and facilitation for initially deviant pairs (Hamburger & Slowiaczek, 1996, 1998; Slowiaczek, McQueen, Soltano, & Lynch, 2000). If immediate processes and long-term processes are similar, we might expect a similar pattern to surface. Any divergence between immediate form priming effects and long-term priming effects would suggest that the former primarily reflect recognition processes whereas the latter are a consequence of how listeners represent speech.

The third and final issue addressed in this article is the role of sublexical information in spoken word recognition. Pseudoword processing is a natural domain for exploration of this issue. To separate lexical effects from sublexical ones, our experiments include prime–target pairs like *jub*–**jup**. These pairs were designed as pseudoword parallels to the word primes and related pseudoword targets (e.g., *job*–**jop**). To the extent that the priming pattern for the pseudoword case diverges from what occurs with word pairs, we can observe the influence of sublexical information that is otherwise masked when examining word processing. The results show that there is indeed a quite different priming pattern for the pseudoword pairs, demonstrating the utility of testing words and pseudowords together in a coordinated way.

We are aware of one other study that examined the long-term effect of real words on the subsequent processing of pseudowords. Monsell and Hirsh (1998) examined the priming effects of words and pseudowords at short and long lags in a lexical decision task. Their main finding was an inhibitory effect between real word primes and real word targets sharing the same initial sound sequence (e.g., *bran*–**brag**). In addition, a facilitative priming effect was found for rime-sharing primes and targets (e.g., *gem*–**hem**). Monsell and Hirsh did examine real word primes followed by nonword probes (e.g., *frog*–**fross**), but the results were not very clear. For example, in their Experiment 1B, there was a nonsignificant inhibitory trend for a real word prime with a pseudoword target. The interpretation is also limited by the fact that participants in this condition performed significantly more accurately (2.6% error rate) on primed targets than on unprimed targets (8.1% error rate). It is therefore not clear whether the longer response times should be attributed to competition processes or to a speed–accuracy trade-off (see Luce, Goldinger, Auer, & Vitevitch, 2000, for a more general critique of the procedures and results of the Monsell & Hirsh, 1998, study). Thus, although there are two existing studies (Monsell & Hirsh, 1998; Sumner & Samuel, 2005) that examined the effect of real words on the later processing of similar pseudowords, neither was specifically designed to examine this inhibitory effect. Moreover, the results are collectively not particularly clean or decisive. Because we believe this effect has the potential to inform models of word recognition, we have conducted additional experiments with better controlled stimuli to establish the reliability of the finding.

In addition to studies examining real word effects on pseudoword processing, there is a large repetition priming literature. Virtually all of the repetition priming literature is based on visual, rather than auditory, presentation, but similar principles may apply. A number of researchers have examined lexical decision performance as a function of prior presentation. These studies have consistently shown that priming a real word decreases both reaction times and error rates for later presentations of that word (e.g., Ratcliff, Hockley, & McKoon, 1985; Scarborough, Cortese, & Scarborough, 1977; Scarborough, Gaerard, & Cortese, 1979; Wagenmakers, Steyvers, et al., 2004).

As Wagenmakers, Zeelenberg, Shiffrin, and their colleagues (Wagenmakers, Steyvers, et al., 2004; Wagenmakers, Zeelenberg, Steyvers, Shiffrin, & Raaijmakers, 2004; Zeelenberg, Wagenmakers, & Shiffrin, 2004) have noted, repetition of a pseudoword has not resulted in the same effect: Some studies have found facilitation for repeated pseudowords (Kirsner & Smith, 1974; Logan, 1990; Scarborough et al., 1977). Others have found no repetition benefit for pseudowords (Brown & Carr, 1993; Forbach, Stanners, & Hochhaus, 1974) or inhibitory effects (Bowers, 1994; McKoon & Ratcliff, 1979). Wagenmakers, Zeelenberg, et al. (2004) have argued that the inconsistent pattern for pseudoword repetition reflects the operation of two opposing factors (cf. Feustal, Shiffrin, & Salasoo,1983). When a pseudoword is repeated, it will seem more familiar, and in a lexical decision task, familiarity enhances a "yes" response, which must be overcome in order to produce the correct "no" response for the pseudoword. On the other hand, having previously made a "no" response to a particular pseudoword provides a practice effect for making the same response to the same pseudoword again, facilitating performance. Zeelenberg et al. (2004) have provided strong evidence supporting this two-process account, showing that changing the study task or the response conditions can tip the relative influence of the two factors.

In this study, we present four experiments examining the effect of hearing a real word on the later processing of a related pseudoword. All four experiments are long-term priming experiments in which participants hear one set of primes in an initial block, followed 10–20 min later by a second block of target items. The first experiment is designed to establish the basic inhibitory effect originally found in Sumner and Samuel (2005) and to verify that the effect is based on the activation (presentation) of a related word, and not the (unpresented) existence of it. Experiment 2 examines whether the inhibitory effect extends to deviations that occur initially (e.g., *beef*–**peef**) and isolates the effect to lexical status and not phonological relatedness (e.g., *beef*–**peef** vs. *baff*–**paff**). The final two experiments examine whether this effect is task specific or whether it generalizes across tasks. These experiments indicate that this is a true perceptual effect and not a strategic one.

Experiment 1A

To explore the inhibitory effect found in Sumner and Samuel (2005) in more detail, Experiment 1 focuses specifically on pseudowords in which the final sound varies from real words by a single feature. We used the same paradigm as in Sumner and Samuel (2005) but included real words ending in a variety of sounds, rather than ones ending only in /t/.

Experiment 1 was run in two parts. Experiment 1A included several conditions that allowed us to establish both the interference effect and a new priming effect for related pseudowords. In order to provide this set of tests, we used groups of tightly yoked stimulus pairs (e.g., *job*–**jop** tests for word–pseudoword priming, and *jub*–**jup** tests for pseudoword–pseudoword priming). Experiment 1B examined whether the word–pseudoword interference effect is due to the mere existence of a real word or to the activation of the real word. This question is most naturally tested by having the same set of pseudoword targets (e.g., **jop**) appear either with no related prime or with the related prime (e.g., *job*–**jop**). The stimuli for Experiments 1A and 1B are listed in Appendixes A and B.

Method

Participants. Sixty undergraduate students participated in Experiment 1A for pay or for course credit. All participants were native speakers of American English. None reported any history of speech or hearing disorders.

Notation. In Experiment 1 and the following experiments, we examined the effect of hearing a prime in one block on the perception of a target in a second block. We denote primes with italics (e.g., *job*) and targets with bold (e.g., **jop**). A prime–target pair is thus *job*–**jop**.

Apparatus. All stimuli were produced by a female phonetician. The words and pseudowords were recorded with a high quality microphone, in a sound-shielded chamber. They were digitized at a 16-kHz sample rate (12-bit A/D) and stored on the hard drive of a PC. The Goldwave (St. Johns, Newfoundland, Canada) sound editing package was used to segment individual items and store them as separate files. During testing, the sounds were reconverted to analog form (16-kHz sample rate, 12-bit A/D) and presented to listeners over high quality headphones. Participants responded by pushing labeled buttons on a response panel.

Materials and design. Sixty monosyllabic English words were used to create the critical stimuli. Pseudowords were formed from these 60 words by changing the final sound by a single feature (20 were changed by the feature voice, 20 by place, and 20 by manner). For example, the pseudoword for the real word *job* was **jop**, in which the only difference between the two items was the voicing of the final sound. Two additional yoked pseudowords were created by changing the vowel of the original word and that of the pseudoword stemming from the real word. These pseudowords also differed from each other only by a single feature in the final sound (e.g., *jub*–**jup**).

The words and pseudowords were used to construct three experimental conditions. The first condition, similar word, involves pseudoword targets (e.g., **jop**) that were similar to word primes (e.g., *job*). The second condition, repeated pseudoword, consists of the same minimally altered pseudoword as prime and target (e.g., *jop*–**jop**). Finally, the third condition, similar pseudoword, contains pseudoword targets that differ from pseudoword primes by a single feature (e.g., *jub*–**jup**). Because these stimuli were directly derived from their yoked bases, the final segment matching procedures in this condition were identical to those used in the similar word condition.

Any difference in priming between the similar word condition and the similar pseudoword condition can be reasonably attributed to the difference in lexicality of the primes in the two conditions. To ensure that any effect was not due to artifactual differences between the target stimuli, we matched the durations of target pseudowords with real word bases (e.g., **jop**) and target pseudowords with pseudoword bases (e.g., **jup**; 586.7 ms and 587.6 ms, respectively). Example stimuli are provided in Table 1.

Three lists were created to counterbalance the items. Each list contained 20 items from each condition, but only one condition for a particular stimulus triplet (e.g., *job*–**jop** vs. *jop*–**jop** vs. *jub*–**jup**). So, each participant received only one pair from a particular set of stimuli in any condition. The real word primes ended in a wide set of consonants (*p, t, k, b, d, g, f, v, s, z*). To control for strategic effects, we added 180 filler items to each block. With the fillers, each block included 120 real words and 120 pseudowords. Filler items were controlled so no consonant–vowel (CV) or vowel–consonant (VC) overlap existed between filler items and critical stimuli.

Procedure. Participants were tested individually or in groups of 2 or 3 in a sound-shielded booth. They were not told at the beginning of the experiment that there would be two blocks of trials. Participants performed the lexical decision task for all trials in both blocks. The presentation of the stimuli was random for

Table 1
Example Stimuli for Experiment 1A

Condition	Prime	Target
Similar word	*job*	**jop**
	dress	**dreff**
	love	**lub**
Repeated pseudoword	*jop*	**jop**
	dreff	**dreff**
	lub	**lub**
Similar pseudoword	*jub*	**jup**
	dreece	**dreef**
	lave	**labe**

each participant or group of participants. For each trial, a participant heard a word or pseudoword, made a decision about that stimulus, and then had 1,000 ms of silence before the next trial began. A new trial was presented without a response if a participant did not respond within 3 s.

Results and Discussion

Response times faster than 500 ms and slower than 2,500 ms (measured from the onset of the target) were excluded from all analyses (3.3% of all responses). Eight participants with error rates above 15% were replaced. Table 2 provides the lexical decision reaction time means and priming effects for this experiment. In the table, the repeated pseudoword condition is used as the neutral baseline for computing priming effects; this choice is based on our finding in Sumner and Samuel (2005) that this condition yields the same reaction times as in the condition with an unprimed target, a result that is replicated several times in the current study.

A single-factor analysis of variance (ANOVA) produced a significant main effect of condition, by-subject analysis, $F1(2, 118) = 21.12$, $MSE = 5{,}127.94$, $p < .01$, and by-item analysis, $F2(2, 57) = 5.44$, $MSE = 4{,}986.03$, $p < .01$. Items in the similar word condition were recognized more slowly than those in the similar pseudoword condition, $F1(1, 59) = 32.93$, $MSE = 2{,}591.93$, $p < .01$, and $F2(1, 38) = 11.27$, $MSE = 2{,}262.01$, $p < .01$. The difference between the similar word condition and the repeated pseudoword condition was significant by subject but not by item, $F1(1, 59) = 5.16$, $MSE = 1{,}947.38$, $p < .05$, and $F2(1, 38) = 1.35$, $MSE = 2{,}012.55$, $p = .253$. Repeated pseudoword stimuli were also identified more slowly than similar pseudoword stimuli, $F1(1, 59) = 19.42$, $MSE = 2{,}569.80$, $p < .01$, and $F2(1, 38) = 4.03$, $MSE = 2{,}668.12$, $p = .052$.

The results of this experiment replicate and extend the pseudoword results of Sumner and Samuel (2005). The results of both experiments show that it is difficult to reject a pseudoword after previously hearing a real word that differs from it by a single feature. This result suggests that the activation of a lexical item affects the later processing of a pseudoword. In Experiment 1A, participants were slower to reject a pseudoword after having heard a similar word than after having recently heard a similar pseudoword. There was also a significant difference between reaction times when the probed pseudoword was actually a repetition of a recently heard pseudoword, rather than merely being similar to it. It is interesting to note that the direction of this difference did not favor true repetition. We noted previously that Wagenmakers, Zeelenberg, et al. (2004) have suggested that repetition of a pseudoword generates two opposing factors, one facilitating and the other inhibiting responses. We suggest that the similar pseudoword condition benefits from most of the facilitation, without the inhibition. We return to this point in the General Discussion, in which we have additional data to consider.

Table 2
Block 2 Reaction Times and Priming Effects for Experiment 1A

Condition	Reaction time (ms) *M*	Reaction time (ms) % error	Priming effect (ms)
Similar word	1122	2.2	−20
Repeated pseudoword	1102	1.3	—
Similar pseudoword	1062	1.7	40

Note. The dash indicates the baseline reaction times to which the other values are compared.

Experiment 1B

Experiment 1A was designed to provide a well-controlled test of the interference effect that we had observed in an unrelated project; our design also allowed us to discover an intriguing facilitation effect in the similar pseudowords condition. However, neither the original study nor Experiment 1A was designed to show whether the interference effect is due to the existence of a related real word or the activation of one. Therefore, in Experiment 1B we manipulated whether listeners heard a related real word approximately 10–20 min before hearing the target similar word pseudoword (e.g., Ø–**jop** vs. *job*–**jop**).

Method

Participants. Twenty undergraduate students participated in this experiment for course credit. All participants were native speakers of American English, and none reported any hearing deficiencies.

Materials. Forty similar word pairs from Experiment 1A were used as stimuli in this experiment.

Design. Two experimental conditions were examined: similar word and new. In the similar word condition, pseudoword targets (e.g., **jop**) had corresponding base real word (e.g., *job*) primes. The second condition, new, consisted of the same minimally altered pseudoword targets (e.g., **jop**), but no corresponding prime was presented in the first block of trials. Any difference in priming between the similar word condition and the new condition can therefore be attributed to the activation of the prime, as opposed to its simple existence. Examples of the stimuli are provided in Table 3.

As in Experiment 1A, Block 2 contained the target pseudowords, and Block 1 contained word primes. Two lists were created for Block 1. Half of the critical real words were included on each list, along with 40 real word fillers and 80 pseudoword fillers. Block 2 contained all 40 critical pseudowords, 40 additional pseudoword fillers, and 80 real word fillers (different from those in Block 1). Therefore, each participant responded to all 40 pseudowords targets but heard corresponding word primes for only 20 of the targets.

Procedure. The procedure was identical to the procedure in Experiment 1A.

Results and Discussion

Response times were measured from the onset of each target item. Responses faster than 500 ms and slower than 2,500 ms were discarded. Two participants were replaced because of high error rates (above 15% incorrect). One item was excluded from all analyses on the basis of a high error rate (52%). Table 4 shows the

Table 3
Example Stimuli for Experiment 1B

Condition	Prime	Target
Similar word	*job*	**jop**
	dress	**dreff**
	love	**lub**
New		**jop**
	—	**dreff**
		lub

Note. The dash indicates that no corresponding prime was presented for the New target words.

lexical decision reaction time means for the target pseudoword stimuli.

A single-factor ANOVA found a significant difference between the two conditions, $F1(1, 19) = 6.03$, $MSE = 2{,}599.68$, $p < .05$, and $F2(1, 38) = 4.10$, $MSE = 2{,}371.04$, $p < .05$. The results of this experiment replicate the pseudoword results of Sumner and Samuel (2005) with stimuli designed to eliminate any artifactual basis for the effect. The current experiment complements the results of Experiment 1A by demonstrating that it is the activation of a real word, rather than its simple existence, that interferes with a listener's ability to reject a related pseudoword later.

It is difficult to reject a pseudoword after previously hearing a real word that differs from it by a single feature even if the prior exposure was 20 min earlier. The results of Experiment 1 are best understood as reflecting competition between the previously activated word and the presented pseudoword. In fact, most current models of spoken word recognition incorporate some kind of lexical competition effect. For example, both autonomous models like the merge model (Norris et al., 2000) and interactive models like the trace model (McClelland & Elman, 1986) have a lexical competition process in which higher activation of one lexical representation produces increased inhibition of other lexical representations. However, the details of lexical competition vary across models. For example, some models emphasize the left-to-right nature of speech and therefore hypothesize that the set of activated (and thus competing) words is primarily determined by the first few phonemes of the input (e.g., the cohort model of Marslen-Wilson, 1990). Other models give equal weight to all of the inputs and consider the competitor set to be all words that diverge from the input by a small amount, typically one phoneme (e.g., the neighborhood activation model; Luce & Pisoni, 1998).

If the inhibitory effect on pseudoword recognition that we have found is in fact due to competition from a previously activated word, then this effect can potentially provide another way of looking at lexical competition. Neither Sumner and Samuel's (2005) study nor Experiment 1 was designed to clarify the nature of the lexical competition. The critical stimuli were pseudowords that diverged from real words in final position (e.g., *job*–**jop**). Such stimuli cannot determine whether the resulting inhibition was due to a cohort effect or a neighborhood effect, because both theories predict competition under these conditions.

In Experiment 2, we changed the position of the altered sound to the beginning of the words (e.g., *beef*–**peef**) and added a new condition and corresponding controls to compare the influence of a related *word* versus a related *pseudoword* on subsequent processing of a pseudoword. This comparison tests whether the effect is due to the previous encounter with a lexical item (e.g., *beef*–**peef**), rather than simply being a matter of phonological relatedness (e.g., *baff*–**paff**). Pairs like *beef*–**peef** should produce the same kind of inhibitory effect as we found in Experiment 1 if the inhibition is due to lexical competition and if competition is based on lexical neighborhoods, because the new stimuli have the same neighborhood relationships as the previous ones (i.e., one phoneme difference between the word prime and the pseudoword target). However, if lexical competition is defined by the initial cohort of similar words, then the presence of different initial sounds (e.g., /bi/ vs. /pi/) should preempt the competition and therefore eliminate the inhibitory effect. In addition, we should see only an inhibitory effect when a related real word has been previously presented (e.g., *beef*–**peef**) and not when a related pseudoword has been previously presented (e.g., *baff*–**paff**).

There is a substantial form-priming literature, but this research has not looked at long-term priming effects. Goldinger, Luce, and Pisoni (1989) examined the identification of words that were phonetically confusable in noise but had no phonemic overlap (e.g., *bull*–**veer**). Targets were identified less accurately following phonetically similar primes than unrelated primes. This effect was observed only with a short interstimulus interval and with low frequency primes. This result is expected if lexical items are organized into neighborhoods. Marslen-Wilson and Zwitserlood (1989) have shown that nonwords that deviate from real words in initial position preclude lexical activation. In a cross-modal semantic priming task, only real words primed semantically related items in Dutch (e.g., *honing* [honey]–**bij** [bee]); nonword primes based on those real words (e.g., *foning*) did not. Marslen-Wilson et al. (1996) examined competitor effects of initially ambiguous monosyllabic primes. In a cross-modal semantic priming task, they found that initial mismatch of a feature or less does not always block the mapping of an input onto lexical representations. Connine, Blasko, and Titone (1993) showed that the degree of deviation should be considered as well. In a series of cross-modal priming tasks, they showed that in addition to the priming found between a real word (e.g., *recent*) and a semantically related target, nonwords that differed minimally (by a single feature, e.g., *lecent*) produced some activation, although not as much as that caused by real words. Maximally different nonwords (those deviating from the base word by more than a feature, e.g., *hecent*) produced no priming. Listeners are also able to process mismatching information when sounds are coarticulated (Gow, 2001). Gow (2001) has shown that listeners are able to use subtle acoustic information

Table 4
Block 2 Reaction Times and Priming Effects for Experiment 1

Condition	Reaction time (ms) *M*	Reaction time (ms) % error	Priming effect (ms)
Similar word	1155	1.5	−38
New	1117	1.6	—

Note. The dash indicates the baseline reaction times to which the other values are compared.

from the speech signal of coarticulated segments to recover underlying information. More recently, Dufour and Peereman (2003) have shown that stronger inhibitory effects occur when primes mismatch targets later in the word (e.g., word-final position), consistent with the cohort model.

Differences between the stimuli and tasks used in Experiment 1 and those used in previous studies make it difficult to directly apply the conclusions of the earlier work here. Connine et al. (1993) examined bisyllabic words in the relevant experiments. It seems likely that a deviation from a longer word is not as crucial as a deviation from a monosyllabic word. For example, when the word *recent* is produced as *lecent*, there are few other words that are a possible match for that nonword. In contrast, when the word *set* is produced as *fet,* the deviation is more critical because it makes up one third of the word and because this deviation is within a single feature of three real words (e.g., *vet, set, pet*). For the monosyllables in Experiment 2, an initial deviation (e.g., *beef*–**peef**) therefore should produce weaker interference effects if the competitor set is determined by the initial cohort.

Experiment 2

Method

Participants. Twenty-four undergraduate students participated in this experiment for pay or for course credit. All participants were native speakers of American English. None reported any history of speech or hearing disorders.

Materials and design. Seventy-two monosyllabic English words were used as the critical base real words. Pseudowords were formed from these 72 words by changing the initial sound by a single feature. For example, the pseudoword for the real word *beef* was **peef**, in which the only difference between the two items is the voicing of the initial sound. Two additional pseudowords were created by changing the vowel of the original word (e.g., *beef* → *baff*) and that of the pseudoword based on the real word (e.g., **peef** → **paff**). Therefore, these pseudowords differed from each other only by a single feature in the initial sound (e.g., *baff,* **paff**), the same featural difference found between the base real word and its related pseudoword. This pair of pseudowords was used to determine if the inhibitory effect is due to lexical competition or phonological relatedness. All stimuli were recorded by the same speaker as in Experiment 1, with the same equipment. The words and pseudowords were used to construct six experimental conditions. Examples of the stimuli are provided in Table 5.

Table 5
Example Stimuli for Experiment 2

Condition	Prime	Target
Similar word	*beef*	**peef**
Repeated (word base)	*peef*	**peef**
New (word base)	—	**peef**
Similar pseudoword	*baff*	**paff**
Repeated (pseudoword base)	*paff*	**paff**
New (pseudoword base)	—	**paff**

Note. Dashes indicate that no corresponding prime was presented for the New target words.

Condition names represent target type. The first condition, similar word, includes pseudoword targets (e.g., **peef**) that are similar to their word primes (e.g., *beef*). In the second condition, repeated (word base), pseudowords derived from word primes are presented as both primes and targets (e.g., *peef*–**peef**). In the third condition, new (word base), the pseudoword target (e.g., *peef*) was primed neither by itself nor by its word base.

Three additional conditions mimicking the initial three were created with pseudoword-based pairs. The fourth condition, similar pseudoword, contains pseudoword targets that deviate from their primes minimally and in the same way as in the similar word condition (e.g., *baff*–**paff**). In the fifth condition, repeated (pseudoword base), the similar pseudoword targets prime themselves (e.g., *paff*–**paff**). Finally, the sixth condition, new (pseudoword base), served as the baseline for the pseudoword pair, so the second member of the pseudoword pair (e.g., **paff**) was an unprimed target with no corresponding prime. As in Experiment 1A, we measured the average durations of the two sets of pseudoword targets (e.g., **peef** vs. **paff**), and again the yoking procedure, coupled with the use of a trained phonetician as the speaker, led to excellently matched stimuli (592.3 ms for the similar word targets vs. 594.2 ms for the similar pseudoword targets).

The conditions above resulted in 72 targets similar to word primes (e.g., *beef*–**peef**) and 72 targets similar to pseudoword primes (e.g., *baff*–**paff**). Two lists were created for Block 2. The first list contained 36 targets similar to real words and 36 targets similar to pseudowords. The second list contained the remaining 36 of each type. Therefore, each participant received a total of 72 critical targets in Block 2, half based on real words and half based on pseudowords, with no overlap within a set. For example, if a participant who received List A was presented with the target *paff*, that participant would not be presented with the target *peef*. We also controlled for CV and VC overlap within lists: Critical primes and targets within subject had no overlapping initial CV or final VC. All fillers began with consonants unused in the initial-deviation condition (e.g., *l, r, m, n, j, w, h, bl, pl, fl, sl*) and ended with vowel and consonant combinations that were not used in the critical stimuli. The stimuli used in Experiment 2 are provided in Appendixes C–E.

For each of the two target lists, three Block 1 lists were created to counterbalance the three conditions for each target type. For example, 24 pseudoword targets based on real words (e.g., **peef**) corresponded to 12 real word primes in Block 1 (e.g., *beef*) and 12 pseudoword primes that were later repeated in Block 2 (e.g., *peef*). For each set of 36 items, only 24 primes were used, creating 12 targets without primes, which serve as the *new* baseline condition. All items were counterbalanced to ensure that each target was paired with all three prime conditions.

In addition to the critical items, filler items were added to each block. A total of 216 filler items were added to each block. Each block contained 72 additional pseudoword fillers and 144 additional real word fillers. Half of the fillers differed from the fillers in Block 2 and half were repeated in Block 2. The high number of fillers and the resulting long lag between primes and targets were designed to avoid strategically based responses.

Procedure. The same procedure as in Experiment 1 was used in this experiment.

Results and Discussion

Response times faster than 500 ms and slower than 2,500 ms were discarded. Two participants were replaced because of high error rates (16% and 21%). Table 6 shows the lexical decision reaction time means for the six experimental conditions. The inhibitory effect for these initial-position deviation stimuli was quite similar to what we found for the final-deviation case.

Statistical analyses confirm this impression. In a single-factor ANOVA, the main effect of condition was significant, $F1(5, 115) = 3.14$, $MSE = 3{,}484.78$, $p < .05$, and $F2(5, 66) = 3.84$, $MSE = 4{,}215.56$, $p < .05$. The crucial comparison is between the similar word condition, and the new (word base) condition, and this difference was reliable, $F1(1, 23) = 5.66$, $MSE = 4{,}351.03$, $p < .05$, and $F2(1, 22) = 23.63$, $MSE = 4{,}046.18$, $p < .01$. The reaction times for repeated pseudowords were virtually identical to those for the new pseudowords, independent of base type ($F1 < 1$ and $F2 < 1$). This result is consistently found in our experiments and presumably reflects the two competing processes for repeated pseudowords: a facilitatory repetition effect and an inhibitory familiarity effect. In addition to the inhibitory effect found for the similar word condition, there was a significant facilitation effect for the similar pseudoword condition (items based on pseudowords, e.g., *baff*–**paff**) relative to the new (pseudoword base) controls, $F1(1, 23) = 8.01$, $MSE = 3{,}164.19$, $p < .05$, and $F2(1, 22) = 4.52$, $MSE = 2{,}728.70$, $p < .05$.

The results of Experiment 2 are very simple to summarize: Exactly the same inhibitory effect that we found for pseudowords created by final-position deviation obtains for pseudowords that were created through initial-position deviation.[1] In addition to providing a strong replication of the previous results, Experiment 2 offers a clear answer to the question we posed about the nature of the lexical competition process. At least for the simple monosyllabic words and pseudowords that were used, the competition can be characterized as neighborhood based, rather than cohort based. If the competitor set were defined on the basis of words that are consistent with the input as it unfolds over time, the similar word condition of Experiment 2 should not have produced the inhibitory effect we had found in Experiment 1; the critical similar word targets differed immediately from their potential primes (e.g., *beef*–**peef**), which would preclude lexical competition. The fact that the same inhibitory effect is generated under these conditions can be taken as evidence for a competitor set that depends on overall similarity, rather than one that emerges dynamically. However, we should add the caveat that more cohortlike effects might appear with longer words and pseudowords. The monosyllables used here (and in a large subset of the word recognition literature; see Pitt & Samuel, 2006, for a discussion of possible differences as a function of word length) may not offer enough of a time–information window to observe differences as a function of position.

We noted in the introduction that in the immediate form priming literature, there have been a number of studies that have found cohortlike differences in monosyllabic words. For example, Slowiaczek et al. (2000) found facilitative priming of words by primes that overlapped finally (similar to our initial-deviation cases, but with pseudoword primes and real word targets, e.g., *peef*–**beef**). Other research examining shared phonological information (Hamburger & Slowiaczek, 1996, 1998) has found similar facilitation for final overlap versus inhibition for primes and targets that overlap initially (similar to our final-deviation cases, but with pseudoword primes and real word targets, e.g., *jop*–**job**). The results of our first two experiments (inhibition regardless of position) clearly contrast with the pattern found in the immediate form priming literature. As we suggested in the introduction, a contrast of this sort implies that the two techniques are tapping different aspects of the system involved in speech processing: The immediate effects reflect properties of the recognition process, and the long-term priming captures aspects of the speech representations. We return to this suggestion in the General Discussion, in which we discuss converging evidence from the final two experiments.

A summary of the effects across the two experiments presented here, as well as those found (but not reported) in Sumner and Samuel (2005), is provided in Figure 1. Independent of the position of deviation (final or initial), hearing a pseudoword after a phonetically similar real word has an inhibitory effect. Across experiments, pseudoword repetition has no effect, and long-term facilitation is found when a pseudoword is preceded early on by a similar pseudoword prime.

We have already noted that the noneffects found for pseudoword repetition priming can be accounted for by a trade-off between familiarity slowing "no" responses and practice speeding up the negative lexical decision to that particular stimulus. The inhibitory effect of a word on the later rejection of a similar pseudoword is consistent with lexical competition processes: A

Table 6
Block 2 Reaction Times and Priming Effects for Experiment 2

Condition	Reaction time (ms) *M*	Reaction time (ms) % error	Priming effect (ms)
Similar word	1010	3.1	−35
Repeated (word base)	976	2.7	−1
New (word base)	975	3.4	—
Similar pseudoword	939	2.9	32
Repeated (pseudoword base)	972	3.5	−1
New (pseudoword base)	971	3.2	—

Note. Dashes indicate the baseline reaction times to which the other values are compared.

[1] Experiment 2 is actually a replication of another experiment we ran that used similar stimuli but that had only four of the six conditions: similar word, repeated (word base), new (word base), and similar pseudoword. For the four conditions shared by the two experiments, exactly the same pattern of results was found: Similar word pseudowords were responded to 51 ms more slowly than new (word base) pseudowords, the repeated (word base) condition was not different from the new (word base) condition (+1 ms), and facilitation occurred for similar pseudowords, as they were responded to 33 ms more quickly than new (word base) control items. For the sake of comparison, we have included the data from this experiment in Figure 1, denoted as Experiment 2A.

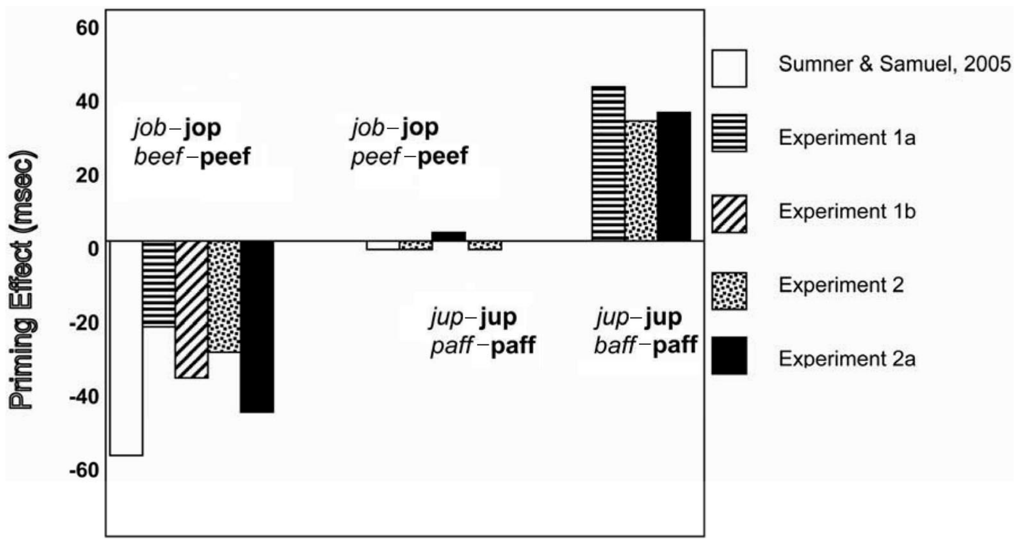

Figure 1. Priming effects from experiments examining lexical and sublexical effects on pseudoword recognition in the long term. Primes are presented in italic, and targets are presented in bold. Experiment 2A refers to an additional experiment that we ran before conducting Experiment 2 (see Footnote 1 for additional information).

word's lexical representation remains active and causes increased competition in rejecting a similar pseudoword. The result with the greatest theoretical potential may be the strong facilitation of sublexical information (shared CV or VC units). This effect may typically be masked by strong lexical effects such as those found in the similar word condition.

The final two experiments are intended to shed more light on the intriguing long-term facilitation we observed for similar pseudowords. This facilitation effect is not as easy to accommodate in many current models as the inhibitory effect. This is because many models do not have an appropriate "place" to put the long-term pseudoword activation: By definition, such stimuli do not have lexical representations that could serve as the site for such long-term resonance. For the moment, we simply suggest that models that posit sublexical units bigger than individual phonemes (e.g., CV and VC units) would be well suited to handle the observed effect. Activation of those units by a pseudoword prime would leave them in a state that would allow faster perception of the target pseudoword sharing these units. Experiments 3 and 4 provide a direct test of this hypothesis.

Although Figure 1 shows an extremely consistent pattern across experiments, one possible concern is that all of these experiments have used the lexical decision task in the second block of trials. As we noted, the use of lexical decision in the second block leaves open explanations that involve decision or strategic effects. If our suggestion regarding the long-term activation of both lexical and sublexical information is in fact representative of a general process in spoken word recognition, then we should find a similar pattern of results across tasks, including ones without this potential complication. The final two experiments provide such a test, using the same stimuli, but with a very different target block task—the identification of speech in noise.

Experiment 3

In this experiment, we examined whether primes presented in an initial block of items, presented in the clear, affect the identification of noise-embedded targets presented in a later set of trials. As we noted, some interpretations of effects found with two blocks of lexical decisions are based on the relationships between decisions made to an item in each block. By using a very different task in Block 2, we preempt any such decision-based effects. In this task, for example, we can examine how participants identify a similar word pseudoword (e.g., **jop**) depending on whether the base real word (e.g., *job*) was presented in the initial lexical decision block of trials. If we observe substantially more attributions of the pseudoword **jop** as *job* when participants are presented with a base real word (e.g., *job*) in the initial block compared with the responses to **jop** when no corresponding real word prime was presented, this would provide direct evidence of the perceptual competition of the lexical prime; any "yes" or "no" response to the primes is orthogonal to the task of reporting the word or nonword embedded in the noise.

The use of a difficult identification task in the target block also provides a very direct way to assess the facilitative effect found between similar pseudowords (e.g., *jub*–**jup**). We suggested that the observed effect on lexical decisions could be due to persistence of CV and VC units from the prime, facilitating perception of the target in the second block, producing faster lexical decisions. If this suggestion is correct, the activation of sublexical units should be task general, not any specific consequence of the lexical decision task being used in both blocks. In Experiment 3, any result of activation of the putative CV–VC units should manifest itself directly in the participants' reports.

For example, if there is lingering activation of the VC unit of the prime *jub*, an increase in reports of items like “lub” or “thub” to the noise-embedded target **jup**, relative to their frequency when no such prime occurred in the first block, should occur.

Method

Participants. Twenty-four undergraduate students participated in this experiment for course credit or for pay. All participants were native speakers of American English. None reported any history of speech or hearing disorders.

Materials and design. The 40 similar word pairs and 40 similar pseudoword pairs from Experiment 1 were used. Four experimental conditions were used: similar word (*job*–**jop**), new (word base) (Ø–**jop**), similar pseudoword (*jub*–**jup**), and new (pseudoword base) (Ø–**jup**).

As in the previous experiments, primes were presented in one block, followed by a second block containing targets. The task of Block 1 was lexical decision in the clear, and the task of Block 2 was the identification of words or pseudowords in noise. All critical targets, however, were pseudowords. The level of noise for each target item was chosen on the basis of the results of a pretest, as described below. Block 1 contained 40 primes: 20 real word primes (e.g., *job*) and 20 pseudoword primes (e.g., *jub*). Two Block 1 lists were created to ensure that only 1 prime from a quadruplet was used. If a listener heard the prime *job*, that same listener would not hear the prime *jub*. The lists were counterbalanced to ensure that each of the 80 total primes was presented to the participants. In addition to the 40 primes, 40 pseudoword and 80 real word fillers were used. Fillers did not overlap with the initial CV or final VC of the critical primes and targets. Block 2 contained 160 items and was the same for all participants. Of the 160 items, 80 were critical pseudowords and 80 were real word fillers. All critical items were embedded in a level of noise established by a pretest, and real word fillers were randomly assigned noise levels with an equivalent distribution to those used for the pseudowords.

Pretest. A pretest was used to establish a noise level for each critical pseudoword target (e.g., **jop**, **jup**) at which listeners can identify the pseudoword. The pretest consisted of 80 critical pseudoword targets (40 similar word targets, e.g., **jop**, and 40 similar pseudoword targets, e.g., **jup**). Twelve participants took the pretest, which was a threshold identification task; none of these participants were tested in the main experiment. Participants were told that they would be listening to pseudowords in decreasing noise levels and to press a button when they could identify all of the sounds in each pseudoword. Each of the 80 critical pseudowords, embedded in 75% noise (i.e., of the total digital amplitude, 75% of the range was allotted to the noise), was presented to the participants. The noise level was decreased in 2.5% steps until a participant pressed a button. At that point, they were instructed to write down the pseudoword. The pretest allowed us to identify the noise level at which each pseudoword was identifiable, as that level may vary across items. To arrive at a noise level for each item for the long-term priming task, the noise level for each item was increased by 50%. So, if the noise level at which pretest participants identified the pseudoword **jop** was 30%, a noise level of 45% was used for that item in the word-in-noise block of Experiment 3. The goal of this procedure was to select a noise level for each stimulus that would yield a rich set of error responses, without an excessive level of guessing.

Procedure. The procedure for the prime block of items was the same as in previous experiments. Participants made lexical decisions to words and pseudowords in the clear. For the target block, participants were given response sheets with 160 lines and were asked to listen to each item presented (once) in noise and to do their best to write down exactly what they heard. They were reminded that both real words and pseudowords would be presented. Participants were given 5 s after the presentation of each item to write down their response before the next item was presented.

Results and Discussion

Error rates for prime responses were used to identify outlying participants. One participant was replaced because of high error rates (23%). The target responses were coded by two coders—Meghan Sumner and a second coder blind to the task. The coders were in agreement 95% of the time, with the remaining 5% of responses not included in the analysis. The majority of the discrepancies were not due to code confusion but to the legibility of the responses.

Responses were coded into the categories shown in Table 7: The label *Target* was used for responses that were identical to the actual pseudoword target (e.g., *jop, jup*); these are the fully correct responses. The label *Target VC* was used when the response included the VC of the target pseudoword, without the correct onset (e.g., *top, yop, cup, chup*). The label *Word* included all instances in which the word base for the similar word targets was identified, independent of whether the target was primed by the word or not (e.g., *job*). We use *Word*, rather than *Prime*, to avoid confusion in the condition when there was no actual presentation of the related prime (the new conditions). The label *Word VC* included those responses (both real words and nonwords) that matched the rime of the base real word (e.g., *cob, tob*). These latter two response types apply only to target items based on words. For similar pseudoword targets (e.g., **jup**), two comparable headings were used: *Pseudoword* included responses identical to the base pseudoword (e.g., *jub*) independent of presentation, and *Pseudoword VC* included items that shared the rime of the base pseudoword (e.g., *dub, lub*). Finally, one response category coded responses that included sounds shared between the prime and target (*Shared CV*) and included responses such as *jock* and *jod* for similar word targets (sharing the CV of the prime *job* and the target **jop**) and responses such as *jut* and *jud* for similar pseudowords.

Twenty target pseudowords for each of the four experimental conditions—similar word, new (word base), similar pseudoword, new (pseudoword base)—were presented in noise. To compute the probability of a particular response type, we took the total number of responses in a particular group (e.g., 7 for response type “Target”) for a particular condition (e.g., similar word) for each participant and divided that number by the total number of responses (e.g., 20).

The probabilities of each response type are provided in Figure 2. The probabilities do not add up to 100% for each condition

Table 7
Scoring System and Sample Responses for Experiment 3 (Final Deviation)

Prime	Target	Response types	Example responses
Real word (e.g., *job*)	Similar word (e.g., **jop**)	Target	jop
		Target VC	top, yop
		Word	job
		Word VC	cob, tob
		Shared CV	jock, jod
—	New (word base) (e.g., **jop**)	Target	jop
		Target VC	top, yop
		Word	job
		Word VC	cob, tob
		Shared CV	jock, jod
Pseudoword (e.g., *jub*)	Similar pseudoword (e.g., **jup**)	Target	jup
		Target VC	cup, chup
		Pseudoword	jub
		Pseudoword VC	dub, lub
		Shared CV	juck, jud
—	New (pseudoword base) (e.g., **jup**)	Target	jup
		Target VC	cup, chup
		Pseudoword	jub
		Pseudoword VC	dub, lub
		Shared CV	juck, jud

Note. Dashes indicate that there was no prime for this condition. VC = vowel consonant; CV = consonant vowel.

because some of the responses did not fall within the categories of interest, because there were no restrictions placed on responses. The top half of the figure shows the results for the new (word base) condition (dark bars) and the similar word condition (light bars). The bottom half of the figure presents the corresponding results for the new (pseudoword base) and similar pseudoword cases.

Word primes. To analyze the data, we compared responses in the similar word condition with responses in the new (word base) condition. A two-factor ANOVA (Condition × Response Type) revealed a main effect of condition, $F1(1, 23) = 23.75$, $MSE = 0.08$, $p < .01$, and $F2(1, 19) = 16.34$, $MSE = 0.10$, $p < .01$; a main effect of response type, $F1(3, 69) = 24.33$, $MSE = 0.06$, $p < .01$, and $F2(3, 57) = 15.55$, $MSE = 0.07$, $p < .01$; and an interaction, $F1(3, 69) = 23.85$, $MSE = 0.07$, $p < .01$, and $F2(3, 57) = 19.26$, $MSE = 0.10$, $p < .01$.

The critical prediction for the word priming condition is that previous activation of the prime should manifest itself as an increase in intrusions of that prime, when the similar pseudoword is encountered under difficult listening conditions. The results provide an unambiguous confirmation of this prediction: Listeners identified a pseudoword in noise as a related real word (e.g., reporting **jop** as *job*) three times as often (27.4%) when a similar real word was presented approximately 10 min earlier than they did without the prime (8.5%). This difference between report of the word base word in the similar word condition versus its report in the new (word base) condition was statistically robust, $F1(1, 23) = 56.23$, $MSE = 0.01$, $p < .01$, and $F2(1, 19) = 38.33$, $MSE = 0.02$, $p < .01$.

Pseudoword primes. For the similar pseudoword versus the new (pseudoword base) conditions, there was a main effect of condition, $F1(1, 23) = 25.67$, $MSE = 0.06$, $p < .01$, and $F2(1, 19) = 32.30$, $MSE = 0.04$, $p < .01$; a main effect of response type, $F1(3, 69) = 5.32$, $MSE = 0.06$, $p < .01$, and $F2(3, 57) = 5.77$, $MSE = 0.07$, $p < .01$; and an interaction, $F1(3, 69) = 16.39$, $MSE = 0.08$, $p < .01$, and $F2(3, 57) = 20.21$, $MSE = 0.05$, $p < .01$.

The predicted priming pattern for a pseudoword prime was quite different than that predicted for a word prime. Recall that we hypothesized that the priming effects we found in Experiment 2 were due to activation of CV and VC units, rather than resonance of the whole pseudoword prime. This view predicts that the intrusions should be items that share the CV or VC of the prime, rather than the prime itself. The data again clearly support the hypothesis: The identification of a target similar pseudoword under noisy conditions (e.g., **jup**) was not influenced by the pseudoword base (e.g., *jub*), $F1(1, 23)=3.00$, $MSE = 0.056$, $p = .157$, and $F2(1, 19) = 1.51$, $MSE = 0.03$, $p = .234$. Rather, presenting a prime significantly boosted intrusions of the pseudoword base VC cases—items that shared the prime's rime, $F1(1, 23) = 55.25$, $MSE = 0.10$, $p < .01$, and $F2(1, 19) = 57.14$, $MSE = 0.07$, $p < .01$. There was a similar increase in report of items that shared the prime's (and the target's) onset CV, $F1(1, 23) = 6.27$, $MSE = 0.09$, $p < .05$, and $F2(1, 19) = 7.28$, $MSE = 0.05$, $p < .05$. These results are compatible with the results found in Experiment 2 and suggest that sublexical units, such as onset CVs and rimes, may remain active and influential over a surprisingly long period of time.

Experiment 3 thus provides additional evidence that (a) lexical items remain active and compete with similar pseudowords in the long-term and (b) sublexical CV and VC units aid in the process-

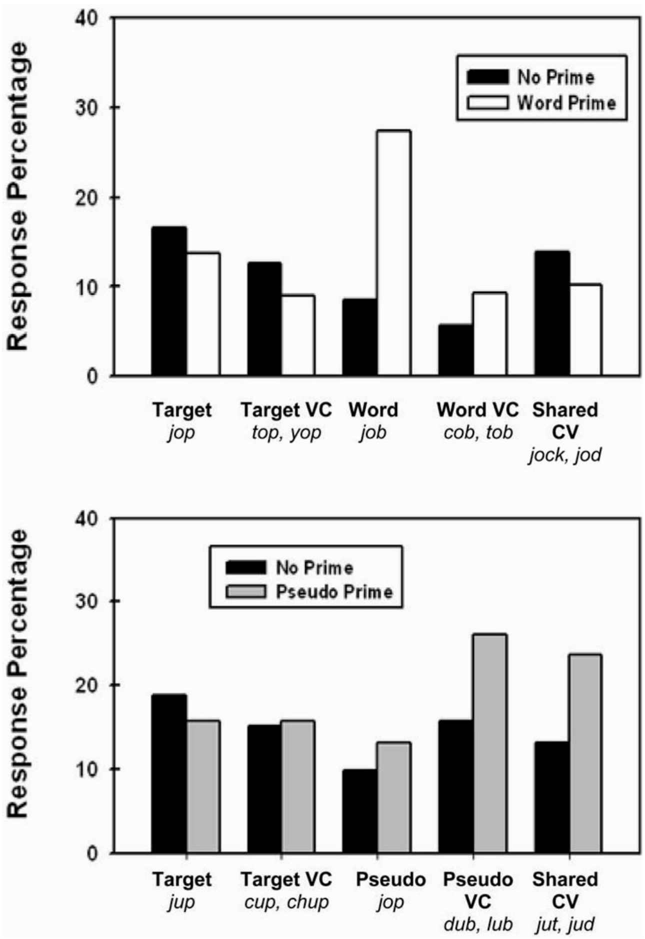

Figure 2. Responses to final-deviation pseudoword targets presented in noise in Experiment 3. The percentages of each response type dependent on prime (word or pseudoword) are plotted. The top graph shows the strong intrusion of word primes on the processing of related pseudoword targets compared with unprimed pseudoword targets, and the bottom graph is contrastive, showing that sublexical chunks intrude more often for pseudoword targets primed by similar pseudowords. VC = vowel consonant; CV = consonant vowel.

ing of phonologically related forms in the long term. Although the basic result has been replicated, an additional experiment is needed to support the claim that this effect is position independent. Therefore, Experiment 4 was run with initially deviant stimuli. Along with Experiment 2, this tests whether lexical items are organized into similarity neighborhoods.

Experiment 4

Method

Participants. Twenty-four undergraduate students participated in this experiment for course credit or for pay. All participants were native speakers of American English. None reported any history of speech or hearing disorders.

Materials and design. Forty quadruplets from Experiment 2 were used in this experiment. The same four experimental conditions used in Experiment 3 were used in this experiment, but the critical manipulation was initial deviation instead of final deviation: similar word pseudoword (*beef*–**peef**), new (word base) (Ø–**peef**), similar pseudoword (*baff*–**paff**), and new (pseudoword base) (Ø–**paff**). The design of the experiment was identical to Experiment 3. Response types and example responses are provided in Table 8. Coding methods were the same as those used in Experiment 3.

Pretest. As in Experiment 3, a pretest with 12 participants was carried out to determine the noise level to be used for each item. The design and criteria used were identical to those used for Experiment 3.

Procedure. The procedure for this experiment was the same as that in Experiment 3.

Results and Discussion

Error rates for prime responses were used to identify outlying participants. Two participants were replaced because of high error rates (17% and 36%). As in Experiment 3, the target responses were coded by two coders. Table 8 lists the coding categories and examples of each type. The probability of a particular response type was computed as in Experiment 3. Figure 3 shows the resulting probabilities, with a format comparable to Figure 2. A comparison of the two figures reveals the most striking result of Experiment 4: The pattern of results for these initial-deviation primes is virtually identical to the pattern for the final-deviation primes of Experiment 3.

Word primes. The data were analyzed as in Experiment 3. A main effect of condition, $F1(1, 23) = 35.61$, $MSE = 0.09$, $p < .01$, and $F2(1, 19) = 15.54$, $MSE = 0.09$, $p < .01$; a main effect of response type, $F1(3, 69) = 26.85$, $MSE = 0.09$, $p < .01$, and $F2(3, 57) = 22.94$, $MSE = 0.06$, $p < .01$; and an interaction, $F1(3, 69) = 55.31$, $MSE = 0.04$, $p < .01$, and $F2(3, 57) = 19.78$, $MSE = 0.01$, $p < .01$, were found for the similar word and new (word base) conditions.

As in Experiment 3, the central question for the word prime case is whether activating a real word prime leads to intrusions when a similar pseudoword is later presented in noise. As Figure 4 shows, real words (e.g., *beef*) presented early on clearly do compete with similar pseudowords (e.g., **peef**) across tasks: The target was more likely to be identified as the word base word when the target was preceded by a word base word than when the target was new, $F1(1, 23) = 14.44$, $MSE = 0.03$, $p < .01$, and $F2(1, 19) = 41.22$, $MSE = 0.02$, $p < .01$.

Different from Experiment 3, however, is the fact that hearing a word base word prime actually lowered the identification rate of the target similar word pseudoword, $F1(1, 23)=32.01$, $MSE = 0.072$, $p < .01$, and $F2(1, 19) = 4.06$, $MSE = 0.05$, $p = .058$. For example, listeners were more likely to identify *peef* as *peef* when it was a new word (22.5% of the time) than when it was preceded by a word base prime (e.g., *beef*; 13.1% of the time). In the same comparison for Experiment 3, $F1(1, 23) < 1$, and $F2(1, 19) = 1.69$, $MSE = 0.01$, $p = .209$. The different outcomes on this point seem to be due to the even stronger priming effect in Experiment

Table 8
Scoring System and Sample Responses for Experiment 4 (Initial Deviation)

Prime	Target	Response types	Example responses
Real word (e.g., *beef*)	Similar word (e.g., **peef**)	Target	peef
		Target CV	peace, peesh
		Word	beef
		Word CV	beep, beeve
		Shared VC	leaf, deef
—	New (word base) (e.g., **peef**)	Target	peef
		Target CV	peace, peesh
		Word	beef
		Word CV	beep, beeve
		Shared VC	leaf, deef
Pseudoword (e.g., *baff*)	Similar pseudoword (e.g., **paff**)	Target	paff
		Target CV	path, pab
		Pseudoword	baff
		Pseudoword CV	bath, bap
		Shared VC	calf, daff
—	New (pseudoword base) (e.g., **paff**)	Target	paff
		Target CV	path, pab
		Pseudoword	baff
		Pseudoword CV	bath, bap
		Shared VC	calf, daff

Note. Dashes indicate that there was no prime for this condition. VC = vowel consonant; CV = consonant vowel.

4, which was sufficiently strong to pull a significant number of target responses out of the response set.

Pseudoword primes. The omnibus ANOVA for the similar pseudoword versus the new (pseudoword base) conditions yielded a main effect of condition, $F1(1, 23) = 6.41$, $MSE = 0.05$, $p < .05$, and $F2(1, 19) = 36.25$, $MSE = 0.030$, $p < .01$; a main effect of response type, $F1(3, 69) = 13.41$, $MSE = 0.06$, $p < .01$, and $F2(3, 57) = 3.24$, $MSE = 0.07$, $p < .05$; and an interaction, $F1(3, 69) = 33.93$, $MSE = 0.05$, $p < .01$, and $F2(3, 57) = 12.68$, $MSE = 0.06$, $p < .01$.

The results for the similar pseudoword (e.g., *baff*–**paff**) were similar to those found in Experiment 3. Hearing a pseudoword base prime (e.g., *baff*) did not lead to more identifications of target pseudowords as the prime, $F1(1, 23) = 1.50$, $MSE = 0.08$, $p = .233$, and $F2(1, 19) = 1.63$, $MSE = 0.07$, $p = .217$. However, a target like **paff** was identified more often as a word or pseudoword sharing the initial CV sequence as the pseudoword base (e.g., *bath*, *bap*) when a pseudoword base prime (e.g., *baff*) was presented, $F1(1, 23) = 64.98$, $MSE = 0.08$, $p < .01$, and $F2(1, 19) = 50.44$, $MSE = 0.06$, $p < .01$. In addition, there was a similar increase in report of items that shared the prime's (and the target's) rime, $F1(1, 23) = 8.82$, $MSE = 0.08$, $p < .01$, and $F2(1, 19) = 7.04$, $MSE = 0.08$, $p < .05$.

Lexical and sublexical effects in Experiments 3 and 4. Overall, the data from Experiments 3 and 4 are extremely similar. A real word prime is more intrusive than sublexical information in the identification of pseudoword targets. However, it is the sublexical units that affect the identification of pseudoword targets when those targets are preceded early on by a related pseudoword prime. The only difference across experiments is the fact that the priming effects were a bit stronger for initially deviant pairs (or equivalently, prime–target pairs sharing rimes). These effects were strong enough to drive down the correct report of the target by causing so many intrusions. The stronger effect for rime-sharing stimuli is not unusual (see Treiman, 1985, 1986, for a similar conclusion).

Figure 4 summarizes the pattern of intrusions, collapsing across the final two experiments. Each plotted point is based on difference scores, taken by subtracting the intrusion rate in the new condition from the corresponding rate in the comparable similar condition. For example, the "Full" data point (i.e., when the full form of the word has an effect on the responses) for the word priming case reflects the 23% higher intrusion rate (19% in Experiment 3, and 27% in Experiment 4) of the entire prime when it was actually presented than when it merely existed.

The pattern is clear: Lexical items produce very large long-term intrusion rates, whereas pseudoword primes rarely surface as target responses. Conversely, the CV and VC components of word primes hardly ever intrude separately, whereas such components are the most frequent responses when a similar pseudoword had been heard previously. This dichotomy can be accounted for if the priming effects are based on the largest chunk of the prime that can be mapped onto stretches of speech that have been encountered with some frequency in the past (Grossberg, Boardman, & Cohen, 1997; see the General Discussion below). For a real word, this span is the whole word, not its parts. A pseudoword, on the other hand, may activate units smaller than the whole because (by definition) there is no existing representation for nonwords. This results in the large number of full word intrusions to pseudoword targets primed by similar words but units smaller than the whole (CV or VC chunks) for pseudoword targets primed by similar pseudowords.

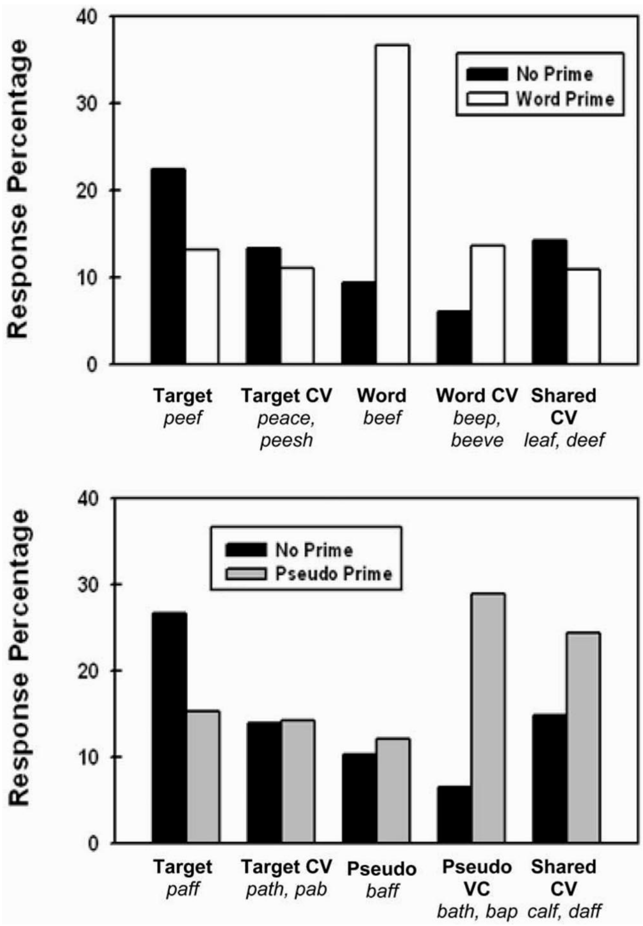

Figure 3. Responses to initial-deviation pseudoword targets presented in noise in Experiment 4. The percentages of each response type dependent on prime (word or pseudoword) are plotted. The intrusion of word primes is replicated for initially deviant prime–target pairs (top). The sublexical intrusions for similar pseudword prime target pairs is evident as well (bottom). CV = consonant vowel; VC = vowel consonant.

Across all four experiments, the data show a neighborhood effect in monosyllabic words that is not task specific. In addition, the results across tasks and across deviation positions suggest that smaller, sublexical units (not limited to those comprising a rime) remain active and are influential in the processing of spoken words. We now consider the implications of these results.

General Discussion

We noted at the outset that most current models of spoken word recognition posit at least two levels of representation, one at the word level and another based on units smaller than a word. The central goal of most research in this domain is to specify the properties of both the lexical and the sublexical units and to clarify the nature of any interactions between units within a level and across levels. In examining the control conditions that we had used in our previous study (Sumner & Samuel, 2005), we found that lexical decisions to pseudowords were inhibited if a similar real word had been presented 10–20 min earlier. Because this finding seemed to offer a new way to explore the processing of lexical and sublexical information, we undertook the experiments reported here. These experiments produced a very systematic pattern of results.

Across all four experiments, we consistently observed an inhibitory effect for pseudowords that were similar to words that had been heard 10–20 min earlier. To our knowledge, the only other study examining this effect is that by Monsell and Hirsh (1998). As discussed earlier, Monsell and Hirsh examined the priming effects of words and pseudowords at short and long lags in a lexical decision task. They examined real word primes and targets, as well as real word primes followed by nonword targets (e.g., *frog*–**fross**). The consistent inhibitory effects found here contrast with a much less stable set of results in the Monsell and Hirsh study. One question we have to ask, then, is why, with similar stimuli, there is such a difference between the two studies. There were substantial differences in the designs of the two studies. Our study included a large number of fillers to mask primes and targets. We also separated the primes and targets into two blocks of items, which provided little opportunity for participants to make a connection between the two or to develop strategic effects. As pointed out by Luce and colleagues (2000), the Monsell and Hirsh design, which consisted of six blocks of 36 items with 12 fillers, 12 primes, and 12 probes each, may have promoted strategic effects. With such a small distance between a prime and its target, it is not unlikely that participants were aware of similarities among stimuli (in fact, Monsell & Hirsh, 1998, reported that some participants were aware of the manipulations at the end of the experiment). In addition, although Monsell and Hirsh did have instances of both facilitation and inhibition in other conditions, it is possible that the stimuli used were not controlled well enough to make a proper attribution of those results.

In the current study, the inhibitory effect caused by having heard a similar word was very stable across experiments. For Experiments 1 and 2, we have noted that a response-based mechanism

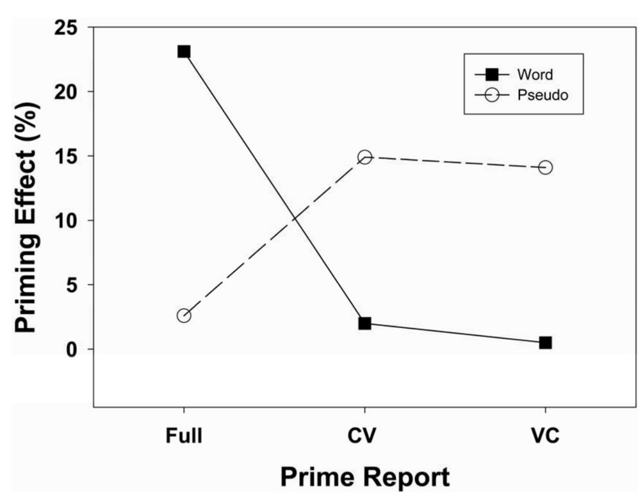

Figure 4. Intrusion rates by response type collapsed across Experiments 3 and 4. Full = the full form of the word has an effect on the responses; CV = consonant vowel; VC = vowel consonant.

could produce the observed result: Responses could be delayed because of the perceived familiarity of the pseudoword, as a result of its similarity to the previously presented word coupled with the experience of having responded "yes" to the similar word. This type of explanation could also potentially explain the faster responses when a pseudoword was primed by a similar pseudoword, as the two similar stimuli both require the same "no" response.

Although this response-based explanation may account for some of the observed priming effects, the high intrusion rates from Experiments 3 and 4 (summarized in Figure 4) indicate that a more perceptual explanation is needed. By changing the nature of the task in the target block, we broke the response-based linkage of previous experiments, yet a very clear pattern of lexical and sublexical priming remained. This suggests that in the pure lexical decision studies at least some of the word priming is due to resonating lexical representations competing with the perception of a similar target pseudoword and to resonating sublexical representations of a pseudoword facilitating the perception of a similar pseudoword.

One of the most surprising results of the current study is the facilitative effect of the near repetition of pseudowords (e.g., *jub*–**jup**, *baff*–**paff**) in Experiment 2 and the strong effect of sublexical information on the identification of pseudowords in Experiments 3 and 4. Although there have been a few studies examining sublexical effects in the visual domain (e.g., Bowers, Damian, & Havelka, 2002), we are not familiar with any long-term auditory priming studies showing this kind of long-lasting sublexical effect. Bowers et al. (2002) examined repetition and form priming effects of printed monosyllabic words. Although some research examining polysyllabic words has not found evidence of partial-form (or sublexical) facilitation (Ratcliff & McKoon, 1997), Bowers et al. found significant lexical and sublexical effects over the long term.

Most models of word recognition are not well suited to accommodate the lasting information that the effect implies. This difficulty can be appreciated by comparing the pseudoword case to a simple word–word long-term priming effect. For the latter, we have noted that a common explanation is that after a word is heard or seen, its lexical representation remains in a state of somewhat higher activation than normal, for some period of time (but see some alternatives discussed below).

If this account is correct, then one must ask how this approach could be applied to the *baff*–**paff** case. The analogous account would be that sublexical representations remain active for the 10–20 min involved in our task. The most common sublexical units in current models of spoken word recognition are at the phonemic level. These do not seem like a promising locus for the long-term resonance needed to account for the *baff*–**paff** priming effect, because during the intervening time listeners hear hundreds of other words and pseudowords that overlap with the sublexical information. This is why we have suggested that a more plausible site for the elevated activation would be chunks that include CV or VC sequences. It is likely that there actually are not many potentially interfering CV or VC units within the set of stimuli that is heard.

Although there is no prior research showing long-term priming by these CV and VC units, there is an existing literature that has looked at such units in other domains. A fairly large number of studies (e.g., Treiman, 1985, 1986; Treiman & Kessler, 1995) have suggested that VC units (rimes) play a much more important role (at least in speakers of English) than CV units (onsets). However, this asymmetry has recently been called into question in child language development (Geudens & Sandra, 2003; Geudens, Sandra, & Martensen, 2005). In the current study, the pure lexical decision task (Experiments 1 and 2) did not show any clear advantage for primes that shared rimes over ones based on CV overlap. The larger effects in Experiment 4 than in Experiment 3, however, do suggest that primes sharing rimes may produce stronger effects than ones whose overlap is in earlier positions. This suggests that the more direct method used in the identification-in-noise task may be more sensitive. The long-term activation at the sublexical level, however it is accomplished, clearly deserves further study.

In general, because the lexical and sublexical effects go in opposite directions, the processing of a pseudoword is much more difficult if a similar word had been presented than if the related utterance had been a pseudoword. This result demonstrates that the long-term priming procedure is very well suited to pulling apart the two opposing processes suggested by Wagenmakers, Zeelenberg, et al. (2004) and provides more information about the nature of the two processes.

The dissociation of lexical inhibition and sublexical facilitation converges with related distinctions made by Pitt and Samuel (1995) and Vitevitch and Luce (1998, 1999). Pitt and Samuel used a phoneme monitoring task to examine lexical activation at different points within three- and four-syllable words, as a function of the size of the initial cohorts. Cohort effects are more likely to emerge with such longer words than with the monosyllables used in the current study. Pitt and Samuel found, as predicted, that lexical cohort size did indeed affect phoneme monitoring—listeners detected targets more slowly when there was greater lexical competition. An unexpected result, replicated several times within the study, was that there was also a facilitative sublexical effect: Targets within high frequency sublexical sequences (e.g., "com," "per") were detected more quickly than targets within less common sequences. This result led Pitt and Samuel to suggest that the word recognition system is sensitive to these sequential sublexical patterns, with more common patterns leading to enhanced recognition (see also Pitt & McQueen, 1998; Warner, Smits, McQueen, & Cutler, 2005).

Vitevitch and Luce (1998, 1999; cf. Bailey & Hahn, 2001, and Luce & Large, 2001) have conducted a series of clever experiments that tease apart the operation of lexical and sublexical processes. Recent work by Lipinski and Gupta (2005; see the reply by Vitevitch & Luce, 2005) has pointed out a potential problem with a subset of the Vitevitch and Luce work, but the overall conclusions of their research program seem secure. Their basic manipulation involved a contrast between neighborhood density (the existence of many similar words defines a dense lexical neighborhood) and high sublexical (phonotactic) transition probabilities (the existence of many instances of one phoneme following or preceding another). Normally, these two factors covary, as the existence of many similar words will usually create a high probability of their common phoneme sequences. But, Vitevitch and Luce (1998, 1999) succeeded in designing stimuli and conditions that could pull these factors apart. These experiments demonstrated that high neighborhood density was associated with greater lexical competition and therefore inhibited performance; high transition probability facilitated performance (Pitt & McQueen, 1998; Warner et al., 2005). This contrast is entirely analogous to the central results of the current study: Activating a word led to slower judgments of a related pseudoword, whereas presenting a pseudoword (and, by our hypothesis, activating its sublexical components) facilitated judgments of a related pseudoword.

In Experiment 2, we found that the repetition of a pseudoword has no effect on reaction times. Our results on this point are consistent with previous studies (most of which were based on printed, rather than spoken, words). Repeating a pseudoword has yielded facilitation (Kirsner & Smith, 1974; Logan, 1990; Scarborough et al., 1977), inhibition (Bowers, 1994; McKoon & Ratcliff, 1979), or as in the current study, no effect (Brown & Carr, 1993; Forbach et al., 1974). The wildly inconsistent outcomes can be accounted for if one assumes that there are two competing effects, with different weighting of the two as a function of the particular experimental conditions (Feustal et al.,1983; Wagenmakers, Zeelenberg, et al., 2004). Zeelenberg et al. (2004) demonstrated that the inhibitory component was favored if the original presentation was not in the context of a lexical decision task, presumably because this change in task removes the facilitative experience of having said "no" to a particular pseudoword previously.

The results of the current study thus add to the growing evidence for the necessity of units of at least two different levels (lexical and sublexical) and for the operation of rather different processes for the two kinds of units. As we have noted, the enduring activation of lexical units, leading to long-term inhibition of related pseudowords, can be accommodated by most current models. However, in most models, it is less clear how to represent the long-lasting activation of sublexical units. The type of model that may be most suited to this problem is some version of Grossberg's adaptive resonance theory (ART; e.g., Grossberg et al., 1997; Vitevitch & Luce, 1999) because this type of model inherently includes sublexical units that could conceivably maintain differences in activation level. The results from Vitevitch and Luce (1999) support the existence of both lexical and sublexical chunks that interact through competitive processes. Vitevitch and Luce showed that the ART approach can be successfully applied to account for the pattern of lexical and sublexical effects. An interesting aspect of this theoretical approach is that there are no a priori theory-based units in ART. Instead, units are organized on the basis of prior experiences: Any stretch of speech that is encountered with some frequency has the potential to become a functional unit (called a *list chunk*) in ART. This approach naturally leads to the existence of representations corresponding to CV, VC, and syllable-sized units, as long as these are present often enough in the individual's history of heard speech.

The key concept in ART is *resonance*. A unit resonates when there is a strong match between the incoming speech signal and an existing chunk. The chunks are considered to be "attractor states," in the sense that input that is similar to a previously encountered pattern will lead to resonance. For example, when a word is heard, there will be resonance between the input word and the stored instances that are most similar to the word (cf. Goldinger, 1998; Goldinger & Azuma, 2003). The greatest similarity, of course, will be to the full word. There will also be resonance to the smaller list chunks making up the word, but a general property in ART is that larger units mask (i.e., inhibit) smaller units.

Note that because of this property, the units that resonate after prior exposure to a real word and to a pseudoword will be different. The largest chunk that resonates for real words will be the whole word. The largest stored chunk matching a pseudoword will be a unit smaller than the whole—for the stimuli in the current study, CV or VC chunks. Consider, for example, a participant hearing the prime *beef*. This will create resonances for phonemes, for CV and VC units, and for the whole word, but through masking, the largest chunk will dominate. When a later presentation of a similar pseudoword is encountered (e.g., *peef*), the input is similar enough to cause resonance of the recently activated *beef*. If a lexical decision to *peef* is required, this will be slowed by the word's competition. If instead the task is reporting the noise-embedded stimulus, the resonating word (the "attractor") will produce a large number of real word intrusions. Note that because of the masking property of larger units onto smaller ones, any effects of the CV and VC attractors will be weak or nonexistent.

With a pseudoword prime, quite a different outcome should ensue. The largest units that can resonate with the input are the CV and VC patterns, which thus become active. If a similar pseudoword target is presented (i.e., one that shares a CV or VC), there will be resonance in the shared chunks. For a lexical decision, this resonance will speed processing of the pseudoword, improving reaction times. And, of course, in the noisy conditions of Experiments 3 and 4, the resonating CV or VC units will intrude. Note that because there are no list chunks corresponding to the original full pseudoword prime, there should not be an increase over baseline in intrusions of the prime, just as we observed.

For these analyses to be correct, the resonance we have invoked must be capable of causing some kind of long-lasting structural changes. This is necessary because the long-term priming procedure provides insights into the representation of speech, in contrast to perceptual effects that seem to be reflected in the results of immediate priming experiments. Two recent studies from our laboratory support this distinction. One of these studies is the project that directly led to the current study (Sumner & Samuel, 2005); the second is a study of the processing and representation of dialectal variation (Sumner & Samuel, 2007). In the Sumner and Samuel (2005) study, we examined how effective three variants of final /t/ are in immediate and in long-term priming. For example, when the final /t/ in *cat* is realized as a glottal stop rather than as the canonical /t/, would *cat* prime *dog* as well as it does with the "normal" /t/? We found that in immediate (form and semantic) priming experiments, all three variants were equally effective primes: The perceptual system allows such variation without any apparent costs. In contrast, in long-term priming experiments similar to those in the current study, strong priming was only found when the Block 1 prime and the Block 2 target both had the canonical /t/ form. This suggests that the representation of words that have been heard tends toward the single canonical variant, even though the perceptual process will accept all three variants.

The results of our study of dialectal variation (Sumner & Samuel, 2007) also illustrate the distinction between a sensitivity to processing parameters in immediate priming and a sensitivity to representational form in long-term priming. The critical conditions in the dialect study involved individuals born and raised in the New York City area. In this area, the local dialect allows "r-dropping": a word like *brother* may be pronounced as "brothuh," with the final *r* replaced by a schwa. We compared immediate and long-term priming effects for two groups of New Yorkers: those who regularly dropped final *r*, and those who did not. For both groups, primes with and without final *r* were effective immediate primes (e.g., both *brother* and *brothuh* effectively primed *sister*). However, for individuals who did not drop *r* in their own productions, primes with dropped *r* were not effective in the long-term priming test. This pattern, like the pattern found for final /t/, suggests that the perceptual system accepts known variants (as shown by reliable immediate priming) but that the representational form (tapped by long-term priming) is more constrained. The contrasting patterns of priming across two sets of experiments strongly support the use of long-term priming to assess representational issues.

The contrast between immediate and long-term priming suggests a difference in the underlying mechanisms that are used to process speech immediately and over a period of time. Bowers (1999, 2000; Bowers et al., 2002) has also found differences between the two types of priming mechanisms with respect to word frequency: Low frequency words benefit more from long-term repetition effects than high frequency words, whereas there is no frequency effect for immediate priming. He suggested (Bowers, 1999, 2000) that long-term priming reflects word learning, whereas short-term priming reflects temporary activation of words. In his view, long-term priming involves structural changes, and these structural changes affect the later processing of repeated items. The work by Bowers and his colleagues used printed rather than spoken words and is therefore based on the orthographic system. Nevertheless, we believe our results can be interpreted along similar lines, with long-term priming based on learning rather than simple activation.

We began this investigation because of the serendipitous finding of a surprising inhibitory effect of real words on the later processing of similar pseudowords. Four experiments and two paradigms later, we have a rich data set that shows two robust phenomena: the original word–pseudoword long-term inhibitory effect and a long-term facilitation of pseudowords on similar pseudowords. As we have just suggested, these two long-term priming effects are consistent with the ART model (Grossberg et al, 1997). It remains to be seen whether other theoretical perspectives can be shown to fit these intriguing results.

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(*Appendixes follow*)

Appendix A

Final-Deviation Stimuli Used in Experiment 1A

Base word: Prime	Similar word pseudoword: Target	Similar pseudoword: Prime	Similar pseudoword: Target
back	bap	boke	bope
bad	bav	bade	bave
bulb	bulp	bilb	bilp
cab	cag	keeb	keeg
cave	kafe	koove	koof
cheat	chead	chit	chid
chef	shev	sheef	sheeve
cliff	cliss	clife	clice
close	clote	clooce	cloot
cough	caup	kife	kipe
crab	crad	crabe	crade
crop	croff	crip	criff
dark	darp	dake	dape
deep	deek	dap	dack
dress	dreff	dreece	dreef
drug	druck	drig	drick
ease	ead	auz	aud
foot	fooce	fot	foss
fuss	fut	foss [fas]	fot [fat]
good	goot	geed	geet
hard	harg	hade	hage
haze	haive	hezz	hev
job	jop	jub	Jup
keg	keck	kug	kuck
land	lant	laund	launt
light	lighp	lut	lup
love	lub	lave	labe
map	maf	meep	meef
mass	mazz	muss	muzz
mob	mov	mab	mav
move	moof	mev	meff
neat	neak	naut	nauk
nerd	nerz	nard	nars
nose	nove	nezz	nev
pig	pid	poig	poyed
pluck	plut	plick	plit
puff	puv	pofe	pove
read	reab	roid	roib
ride	ribe	raud	raub
rose	roce	rizz	riss
self	selp	solf	solp
sharp	shart	shope	shote
ship	shiff	shope	shofe
sled	slet	slood	sloot
slip	slib	slape	slabe
slug	sluck	sleg	sleck
solve	solb	silv	silb
speak	speat	spuck	sput
stop	stot	stup	stut
sub	suv	soob	soove
top	tob	tep	teb
track	trag	trake	trage
tub	tud	tib	tid
twig	twick	twag	twack
vase	vate	vauss	vaught
verb	verp	varb	varp
voice	voize	vess	vezz
wait	wace	woot	wooce
web	wev	wibb	wiv
wife	wice	woff	woss

Note. The similar word pseudowords were used in the repeated and new pseudoword conditions.

Appendix B

Final-Deviation Stimuli Used in Experiments 1B and 3

Word base: Prime	Similar word pseudoword: Target	Pseudoword base: Prime	Similar pseudoword: Target
bulb	bulp	bilb	bilp
cave	kafe	koove	koof
cheat	chead	chit	chid
chef	shev	sheef	sheeve
cliff	cliss	clife	clice
cough	caup	kife	kipe
crop	croff	crip	criff
dark	darp	dake	dape
deep	deek	dap	dack
drug	druck	drig	drick
ease	ead	auz	aud
good	goot	geed	geet
hard	harg	hade	hage
haze	haive	hezz	hev
job	jop	jub	jup
keg	keck	kug	kuck
land	lant	laund	launt
light	lipe	lut	lup
love	lub	lave	labe
map	maf	meep	meef
nerd	nerz	nard	nars
pig	pid	poig	poyed
pluck	plut	plick	plit
read	reab	roid	roib
ride	ribe	raud	raub
rose	roce	rizz	riss
self	selp	solf	solp
sharp	shart	shope	shote
slip	slib	slape	slabe
slug	sluck	sleg	sleck
solve	solb	silv	silb
speak	speat	spuck	sput
top	tob	tep	teb
track	trag	trake	trage
tub	tud	tib	tid
twig	twick	twag	twack
verb	verp	varb	varp
voice	voize	vess	vezz
wait	wace	woot	wooce
wife	wice	woff	woss

(*Appendixes continue*)

Appendix C

Initial-Deviation Stimuli Used in Experiments 2 and 4

Word base: Prime	Similar word pseudoword: Target	Pseudoword base: Prime	Similar pseudoword: Target
	List A		List B
bass	dass	boice	doice
bathe	vathe	bith (∂)	vith (∂)
beef	peef	baff	paff
boot	doot	brit	drit
catch	gatch	kertch	gertch
chair	jare	cher	jer
chat	jat	cheit	jeit
cheat	jeet	chit	jit
chef	feff	shiff	fiff
dame	zame	dem	zem
deep	zeep	dape	zape
did	zid	derd	zerd
feat	veat	fert	vert
fib	thib (θ)	feeb	theeb
gag	cag	gaug	caug
gaze	caze	gizz	kizz
gel	chell	cheel	jeel
gig	kig	geeg	keg
goof	koof	geff	keff
paid	taid	proid	troid
path	fath	pauth	fauth
peach	keach	peitch	keitch
peg	teg	perg	terg
pith	bith	peeth	beeth
sash	tash	sish	tish
sham	tham	shoim	thoim
shape	thape	shap	thap
sing	shing	sєng	shєng
theme (θ)	theme (∂)	thame (θ)	thame (∂)
there (∂)	there (θ)	thaur (∂)	thaur (θ)
thin (θ)	thin (∂)	thern (θ)	thern (∂)
tiff	siff	teef	seef
vague	fague	veg	feg
van	zan	veen	zeen
vow	zow	voi	zoi
zen	sen	zaun	saun
	List B		List A
tube	poob	tawb	pawb
food	vood	fawd	vawd
zoom	soom	zome	some
june	chune	jᴜn	chᴜn
shoe	thew	shoi	thoi
took	pook	tuke	puke
good	dood	gaud	daud
soot	zoot	sert	zert
full	shull	frul	shrul
bush	vᴜsh	boosh	voosh
comb	gome	kawm	gawm
soap	zope	sᴜp	zᴜp
tone	done	toin	doin
boat	poat	poit	boit
vogue	fogue	vug	fug
chore	jore	cher	jer
paw	baw	proy	broi
dog	zog	doog	zoog
taunt	saunt	tunt	sunt
far	var	foor	voor
shot	fot	shote	fote
sop	zop	sawp	zawp
pond	tond	pᴜnd	tᴜnd
dock	gock	doke	goke

Appendix C

(continued)

Word base: Prime	Similar word pseudoword: Target	Pseudoword base: Prime	Similar pseudoword: Target
bob	vob	bobe	vobe
jog	chog	jogue	chogue
thong (θ)	thong (∂)	thung	thung
cub	gub	kʊb	gʊb
pug	fug	paug	foug
bun	vun	boin	voin
dove	tove	derve	terve
such	zuch	souch	zouch
thumb	shum	thoim	shoim
chuck	juck	chouk	jouk
gown	kown	gern	kern
shout	fout	shrote	frote

Appendix D

Experiment 2 Real Word Fillers

blab	lake	moth	rime	wed
bleak	lamb	mouth	rip	weed
bleed	lane	move	ripe	wean
blip	laugh	mum	rise	we're
bliss	lead	nab	rod	wet
blotch	leak	neat	roll	whale
bluff	lean	neck	rove	wham
flab	lease	need	rum	wheat
flake	leash	nice	rung	when
flat	leave	nick	rush	while
flawed	leer	niece	slab	whip
flee	lice	night	slain	whirl
fleece	lick	nip	slam	white
fleet	light	nod	slave	whole
flight	like	noose	sled	why
flip	limb	notch	sleek	wick
fluff	lime	numb	sleet	wide
flung	line	nurse	slick	wife
flush	lip	place	slight	wine
fly	live	plague	slim	wipe
gnaws	loaf	plaid	slime	wise
hail	log	plane	slip	wish
half	loop	play	slum	witch
ham	loose	plead	slurp	worm
hat	lose	pleat	slush	worse
have	lung	plight	sleuth	worth
head	lurk	plum	sly	yale
heat	mace	plus	snake	yam
heed	mad	plush	sneak	yard
height	mail	race	snip	yeah
here	main	rail	snitch	year
hide	make	rain	street	yen
hike	mat	ram	strove	yet
hill	mean	rat	strum	young
hip	meek	ray	wake	youth
hiss	meet	read	walk	yum
hitch	men	real	wall	
hoop	mere	rear	wash	
house	mead	red	watch	
hum	mill	reek	wave	
hype	mime	rice	way	
knife	miss	rich	we	
lab	mode	ride	weak	
lace	mole	right	weave	
lad	moose	rim	web	

(*Appendixes continue*)

Appendix E

Experiment 2 Pseudoword Fillers

blaum	mim	wofe
blerth	mipe	wooce
blibe	mipe	woog
blife	mive	wooth
bloss	naff	woove
blup	nawf	wudge
flazz	nawsh	wung
floaf	nazz	yabe
floog	nen	yace
flum	nep	yague
flutch	nesh	yake
habe	nodge	yean
hake	nofe	yeave
hawb	noop	yeb
hawsh	noove	yeed
heb	noshe	yesh
heece	nung	yev
heek	pleak	yill
heen	plean	yitch
hep	pleb	yiv
hiv	plen	
hoce	plet	
hofe	plice	
hoff	Pliss	
hudge	raub	
huth	raum	
laush	raup	
lauv	roff	
lauz	ross	
lerm	rotch	
lerp	rov	
lerth	rowdge	
lerz	rowth	
loip	rozz	
loit	rup	
mabe	russ	
maig	ruzz	
meb	wab	
meece	waff	
meesh	wav	
meeve	wazz	
meith	weck	
mibe	woce	
mife	woche	

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