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Sounds of the Neighborhood: False Memories and the Structure of the Phonological Lexicon

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The development of a well-formulated view of the memory storage systems (lexicons) involved in word recognition is a central goal of research on language processes. Assumptions about the organizing characteristics and structures of these memory systems are found in various discussions of lexical neighborhoods (Coltheart, Davelaar, Jonasson, & Besner, 1977) or cohorts (Johnson & Pugh, 1994; Marslen-Wilson, 1990). The focus of neighborhood research in visual word recognition has been primarily at the orthographic level. Several articles have discussed how orthographic neighborhood effects provide insight into the manner by which visual words are translated into sound and meaning during reading. In this article, we move the investigation to the phonological lexicon in an attempt to establish the word characteristics that best reflect phonological lexical organization. We describe two phonological false memory experiments that demonstrate that the initial two phonemes of phonological CVC words play a central role in predicting false memories for unpresented items. We also provide evidence of sustained and complementary activation when lists of items provide converging information about the unpresented critical lure.

Keywords: phonological access; reading; lexicon; false memory.

Research on word recognition has a necessary and fundamental relationship with memory processing. Discussions of word recognition must be founded on some implicit or explicit theoretical commitment regarding the means by which words are represented, stored, and retrieved during reading. Despite this necessary connection, there has been little explicit interaction between the memory and word recognition research domains. The purpose of this study is to establish the guiding properties of spreading activation in the phonological lexicon during word reading and, thereby, to constrain our understanding of the functional layout of phonological neighborhoods resident in memory. To get at these issues, we used an increasingly popular memory paradigm—the false memory or the Deese (1959)/Roediger & McDermott (1995) (D/RM) paradigm.

The most influential models of word recognition assume that relationships between different words or their components determine the spread of activation (e.g., Coltheart, Curtis, Atkins, & Haller, 1993) or the extent of shared activation between memory representations of words (e.g., Plaut, McLelland, & Seidenberg, 1996). A full specification of such models requires some stipulation of the properties by which this spread or sharing of activation occurs. In Coltheart et al.'s (1993) dual route cascade (DRC) model, the arrangement of the various lexicons reflects similarity along the defining dimension of each lexicon. For example, in the orthographic lexicon, words that share many letters with a stimulus word are more likely to receive spreading activation on presentation of that word than are words that share fewer letters. In Plaut et al.'s (1996) parallel distributed processing (PDP) model, similar words share common sublexical nodes that become active during word reading. Words that have many letters in common with a target word have more of their constituent representations active than do words with little overlap.

The different assumptions about whole-word versus subword activation underlie the manner by which these two models process single written words and form the basis of investigations of neighborhood (e.g., Jacobs & Grainger, 1992; for a review, see Andrews, 1997) and priming effects (e.g., Neely, 1991) in word recognition. In the area of auditory word recognition, phonological processing has received considerable attention, and models of auditory word recognition

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often assume a cohort or neighborhood activation spread similar to that for orthography in visual word recognition models (e.g., Newman, Sawusch, & Luce, 1997).

Fewer studies have investigated phonological neighborhood effects during visual word recognition, as we do in this study. A priori, there are no necessary limitations on the characteristics that guide the spreading of activation during word reading between phonologically related words. Activation from one entry in the phonological lexicon to other entries might spread by as many routes as there are phonological features—or even combinations of features—in the initial entry. However, it is more likely that some properties play a greater role than do others. We use the false memory paradigm (Deese, 1959; Roediger & McDermott, 1995) and adopt a simple familiarity-based recognition account with two assumptions. First, we assume that spreading activation between related phonological representations gives rise to familiarity with unpresented but related items (Collins & Loftus, 1974; Underwood, 1969). Second, we assume that this increased familiarity makes participants more likely to produce false memories (Brown, Buchanan, & Cabeza, in press). Many experiments have shown that false recognition increases as a function of the extent of the relation between unpresented lures and the words presented in the study list. This appears to be true regardless of whether the relation is semantic (Buchanan, Brown, Cabeza, & Maitson, 1999; Deese, 1959; Read, 1996; Roediger & McDermott, 1995) or phonological in nature (Schacter, Verfaellie, & Anes, 1997; Sommers & Lewis, 1999; Wallace et al., 1995; Wallace, Stewart, Shaffer, & Wilson, 1998).

Using this paradigm, we investigate the extent to which activation sharing/spreading for phonetic CVC words, as measured by false memories, is predicated on three features: (a) the initial phoneme (IP), (b) the first two phonemes (head), and (c) the final two phonemes (rime). Evidence suggests that all three of these features play a role in phonological activation, although direct comparisons of their contributions are rare. We begin with a brief review of the evidence implicating each of these three features.

The Role of the IP

Evidence implicating the IP in spreading activation between entries comes mainly from the auditory domain. Studies of the “tip of the tongue” (TOT) phenomenon show that some participants report that they feel almost able to recall a low-frequency word that they cannot actually produce (Brown & McNeill, 1966; Caramazza & Miozzo, 1997; Miozzo & Caramazza, 1997). These participants were sometimes able to produce the first phoneme of a word that they were unable to produce in its entirety, thus suggesting that activation from the unretrieved word made contact with the representation of the IP. This set of findings is primarily relevant to auditory word production. However, indirect support for the claim that the IP also plays a special role in phonological activation in visual word recognition comes from the work of Treiman, Mullennix, Bijeljac-Babic, and Richmond-Welty (1995). In their examination of the statistical properties of printed words, Treiman and her colleagues showed that word-naming reaction times are significantly correlated with pronunciation consistency (compared to orthographic neighbors) of the first phoneme (but not the first two phonemes) in three-phoneme words.

The Role of the Rime

In the same study, Treiman and her colleagues (1995) also showed that naming reaction times for low-frequency words correlated significantly with pronunciation consistency measures of the rime but not of the head. This finding is consistent with claims by Patterson and Morton (1985) that the rime is an important feature for phonological assembly. Treiman et al. (1995) argued that one reason for the importance of the rime in phonological assembly is that the final consonant in a phonological CVC string places stronger constraints on the pronunciation of the vowel than does the initial consonant (Stanback, 1992). This suggests that the rime may have a better likelihood of activating neighbors than the head simply by virtue of its greater pronunciation consistency. Evidence supporting this posited role for rime activation has been reported by some researchers (Andruski, Blumstein, & Burton, 1994; Connine, Blasko, & Titone, 1993; Magnuson, Tanenhaus, Aslin, & Dahan, 1999; Slowiaczek, Nusbaum, & Pisoni, 1987). However, arguments against the activating role of the rime have also been presented. Marlsen-Wilson and his colleagues examined the priming effect of rimes in several different ways between modalities and within a single modality (Marlsen-Wilson, van Halen, & Moss, 1988 [as reported in Marslen-Wilson, 1990]; Marslen-Wilson & Zwitserlood, 1989; Moss & Marslen-Wilson, 1989 [as reported in Marslen-Wilson, 1990]). The results of this series of experiments were uniformly negative; none of the experiments found any priming effect attributable to rimes.

The Role of the Head

Earlier work by Jakimik, Cole, and Rudnicky (1985) and by Marlsen-Wilson and his colleagues (reported in Marlsen-Wilson & Zwitserlood, 1989) also used priming to show a role for the head in the spread of activation between phonological representations. Jakimik et al. (1985) found that priming in an auditory lexical decision task occurred, for both word and nonword targets, only when part of the prime shared both the same sound and the same spelling with the probe. This finding underscores the need to analyze both orthographic and phonological overlap in activation studies. Recent work in lexical decisions (Monsell & Hirsh, 1998) has provided further evidence that the head plays a primary role in the spread of phonological activation. The results of that set of experiments, which systematically manipulated the interval between presentation of the prime and probe, suggest that head-related activation remains in the lexicon for up to 5 min.

Evidence from the false memory paradigm supports the role of the head in spreading activation (Wallace, Stewart, & Malone, 1995; Wallace, Stewart, Sherman, & Mellor, 1995; Wallace et al., 1998). Wallace and his colleagues have been investigating the claims of cohort theory (e.g., Johnson & Pugh, 1994; Marslen-Wilson, 1984, 1987) in spoken word recognition using the false memory paradigm for a number of years. Wallace et al. (1998) investigated the extent to which early (i.e., melancholy → belancholy) versus late (i.e., melancholy → melanchoby) phonemic changes in auditorily presented nonwords would result in later familiarity (as measured by the number of false memories) for unheard items. Although both early and late phonemic changes resulted in some false memories compared to control items, changes at the end of the letter string were more likely to produce false memories than were changes at the beginning of that string. Greater overlap resulted in more false memories than conditions in which items had fewer phonemes in common. The results of these experiments support the notion that any phonological overlap can result in some increase in subjective familiarity for unpresented items, a notion that is consistent with a spreading activation view of lexical access. However, the fact that late changes produced more false memories than early changes suggests that activation is most likely to spread as a function of phonemes at the beginning of the word.

Wallace, Stewart, Sherman, and Mellor (1995) included one experiment that looked at visually presented words. They showed that such words followed the same pattern as the auditorily presented words, with more false memories occurring for words with overlap in the early phonemes than for words with overlap at the end. However, that experiment lacked control for many word characteristics (word frequency, word morphology, number of orthographic neighbors, degree of orthographic overlap between study and test items, and phonological length), rendering the results difficult to interpret.

To summarize, studies of the TOT phenomenon suggest that phonological activation may spread by the IP, data from word-naming reaction times suggest that the rime of a word enjoys special status in phonological assembly to the extent that it is considered as a single unit, and work using the false memory paradigm suggests that activation spread within the phonological lexicon for spoken words is stronger when the heard and unheard words share early phonemes.

False Memory Experiments

The assumption that false memories for critical lures arise because those unpresented words have been strongly primed suggests that differences in false recognition rates have implications for theories of word recognition (Buchanan et al., 1999). It is possible to precisely control the number of phonemes in common between the critical lure and studied list items. It is also possible to select words that resemble the critical lure in different, linguistically meaningful ways while holding the number of overlapping phonemes constant. This level of control makes it possible to directly test hypotheses about the structure of the phonological lexicon. The cohort model (Johnson & Pugh, 1994; Marslen-Wilson, 1990) predicts that experience with head-related word sets will prime related words more strongly than will experience with rime-related word sets. Treiman et al.'s (1995) view that the rime plays a special role in word recognition suggests the opposite prediction.

The issue of which part of the word plays the most important role in phonological access has not been specifically addressed in the literature, despite the presence of a handful of phonological false memory experiments. Schacter et al. (1997) and Sommers and Lewis (1999) both reported relatively high false memory rates for their phonological lists, but their lists mixed heads with rimes. Wallace et al. (1998) differentiated heads from rimes but did not control for syllable or phoneme length or for number of overlapping and nonoverlapping phonemes.

In the current study, we address the limitations of previous studies with a stringently controlled set of word lists. We restricted ourselves to phonological CVC words and manipulated phonological overlap of the nonpresented critical lure to studied words in three ways. In the Rime overlap condition, the list items shared the final two phonemes with the critical lure (e.g., *bake* is a critical lure for a list that includes *wake*, *make*, and *sake*). In the Head overlap condition, the list items shared the same two initial phonemes (e.g., *bake* is a critical lure for a list that includes *bade, bane*, and *beige*). In the IP overlap condition, the list items shared only the first phoneme (e.g., *bake* is a critical lure for a list that includes *ball, binge,* and *belt*). Our goal was to determine the extent to which the instantiated relationship guides spreading activation within the phonological lexicon, as measured by false memory rate.

We conducted two experiments, based on previous pilot studies. Participants were randomly assigned to one of the two experiments.

EXPERIMENT 1

The first experiment addresses two issues. First, we directly test the prediction that increased phonological overlap produces increased false memory rate. Second, we contrast head overlap with rime overlap to determine whether head overlap produced more false memories than rime overlap, as the Marslen-Wilson cohort theory predicts. In this experiment, therefore, we directly compare the extent that shared heads, rimes, or IPs produce false memories during silent reading of study lists.

Method

Participants

A total of 49 undergraduate participants participated in this study to receive course credit. All were native English speakers.

Procedure

In this experiment, we manipulated the relation of words in a study list to words in a recognition list, using the number of false memories to stimuli on the recognition list as the main dependent measure of interest. Although the methodology is quite simple, the stimulus sets are complex. We begin by outlining the methodology. In the following section, we explain in detail how the stimulus sets were constructed.

The experiment consisted of 10 cycles through three phases: the study and test phase, separated by a 2-min distractor task. Both the experimental and distractor tasks were explained to participants before they began.

The first cycle was a practice list, using test and study lists containing items that did not appear in the other lists. Results from this cycle were discarded.

During the study phase, each participant studied the 10 words in the study list. The words were presented on a PC-controlled video monitor for 2,000 ms. Each presentation was preceded by a fixation cross for 500 ms and followed by a blank screen for 500 ms.

After all 10 words had been displayed, the participant was instructed to begin a distractor task via a message appearing on the computer screen. The task required the participant to trace a path between two points on a paper maze. This task was explained to each participant before the experiment began. Each participant was supplied with a pencil and more mazes than he or she could possibly complete during the course of the experiment.

Two minutes after instructing participants to begin the maze task, the computer sounded a beep to signal that the test phase was to begin. In this phase, participants saw each word in the test list. They were instructed to decide as quickly and accurately as possible whether they had seen each word previously in the study list. They signaled their decision by pushing one of two specified keys on the keyboard. Right-handed participants used the “/” key to signal a “yes” response (indicating that they had previously seen the word) and used the “z” key to signal a “no” response (indicating that they had not previously seen the word). To ensure that the “yes” response was always under the control of the dominant hand, left-handed participants used the reverse response pattern.

Stimulus set construction. The test and study lists were composed of words drawn from 9 stimulus sets. The lists were constructed, by computer-aided dictionary search, around 9 English CVC critical lures identified in the WordMine database (Buchanan & Westbury, 2000) as having a large number of phonological neighbors. These stimulus sets are reproduced in Appendix A. Along with the critical lure, each stimulus set contains at least 8 English three-phoneme words related to that lure in each of four ways:

1. Words in the Head condition shared the same two IPs with the lure.
2. Words in the Rime condition shared the same two final phonemes.
3. Words in the IP condition shared the same IP.
4. Words in the Unrelated condition had no phonemes in common with the critical lure.

The total number of stimuli in all 9 sets was 300, not including the 9 critical lures. This number is greater than the product of 9 lures * 4 categories * 8 members per category = 288. The reason is that when we were able to find more than 8 words fit into a condition, those additional words were also included. No set contained homophones or words that the authors identified as having strong emotional connotations. We thereby excluded expletives, words connected with sexual or expulsive bodily functions, and words with strong religious connotations.

Our method of item inclusion strays from standard practice. Because this is so, we take time here to describe and justify our inclusion policy.

In creating word lists for the D/RM paradigm, most researchers limit the related items to the number required to provide lists of equal length and then expose all participants to the same lists. The problem with this policy is that individual words have many specific qualities that are known to play a role in word recognition (for reviews, see Coltheart et al., 1993; Plaut et al., 1996). It is well established, for example, that the frequency with which a word is encountered is inversely correlated with word access times in both lexical decision and naming (e.g., Balota & Spieler, 1999; Coltheart et al., 1993; Ferrand & Grainger, 1996; Gerhand & Barry, 1998; Lukatela, Frost, & Turvey, 1998; Lupker, Brown, & Colombo, 1997; Plaut et al., 1996; Ziegler & Perry, 1998). Similarly, the number of words that share all but a single letter with the target word (orthographic neighborhood size) has been shown to have an impact on word access times (e.g., Johnson & Pugh, 1994; Sears, Hino, & Lupker, 1995, 1999; Sears, Lupker, & Hino, in press). Even syllable frequency plays a complex role in determining reading speed and accuracy (Perea & Carreiras, 1998). The relation between lexical access times and spreading activation is not clearly specified. However, access time effects are usually assumed to reflect lexical organization. Therefore, they must be taken into account in studies that purport to examine spreading lexical activation.

Unfortunately, it is very difficult (and often demonstrably impossible by an exhaustive dictionary search) to systematically control for all of these variables, especially when other constraints on word selection are imposed by an experimental design. There are simply too many dimensions of variation spread across too few available words. To limit the potential problem of word-specific effects, therefore, we opted to control for their effects in the experiments reported here by randomizing across the variables to the greatest extent possible. To do so, we included every potential candidate we could find in the Head and Rime categories in the initial stimulus set and devised an algorithm to assign items randomly to their relevant lists for individual participants. The result is that not every participant in the experiment saw exactly the same list of words associated with each critical lure. Every participant did, however, see lists of the same length that were related to the critical lures by exactly the same overlap relations. By including all available words, defining all overlap relations for every critical lure, and randomly selecting from this pool for each participant, we increased the likelihood that our results reflect language functionality in general rather than reflecting an effect specific to one particular list of words (Clark, 1973).

Although a few words appeared more than once in different categories, no participant saw the same word twice. This control was imposed by eliminating any stimulus sets in which, for example, *bail* was a head neighbor for *bake* and a rime neighbor for *rail*.

Statistical properties of the stimulus set. An analysis was conducted on the statistical properties of the stimulus set by word category (Head, IP, Rime, and Unrelated). Six (2%) of the words (*wiff*, *kook*, *tad*, *peet*, *gail*, and *geek*) did not appear in the WordMine database (Buchanan & Westbury, 2000) that we used for the analysis and so could not be entered into the analysis. We conducted three sets of analyses: one looking at the orthographic neighborhood, one looking at the phonological neighborhood, and one comparing the orthographic and phonological overlap of the critical lures to the stimuli in their related categories.

Among the remaining 294 words, the four categories of words did not differ significantly in terms of the average orthographic frequency of the words or the number of orthographic neighbors, $F(3,294) < 1$, $p > .05$ in all cases.

Words in the Head and Rime categories necessarily differed from at least 16 words (the critical lure plus the 15 other words in the Head and Rime categories for that critical lure) by only one phoneme in a specified location. Because of this, they necessarily have a high number of phonological neighbors. As a result, there was a significant difference between the groups in terms of the number phonological neighbors, $F(3,294) = 10.4$, $p < .001$.

For comparison purposes, we calculated an average population estimate of phonological neighborhood size (Fig. 1). We randomly selected exactly 20 times as many words of each length (three to six characters) as appeared in the experimental stimulus set and used the average number of phonological neighbors of that large length-matched set as a population estimate. Our definition of the phonological neighborhood allows multiple word entries if they appear as distinct entries (because of belonging to different syntactical categories) in our dictionary including multiple entries of the target word. Stimuli from the Unrelated category were the only stimuli not required by their very definition to have a large number of phonological neighbors. Their average number of phonological neighbors was 0.5 standard scores above the population estimate. All other stimuli categories had a high average number of neighbors and a small standard deviation compared to the population average. Most important for the analyses we present here is that there was no significant difference in the average number of phonological neighbors of words in the Head and Rime categories, $t(70) = .05$, $p > .50$.

Each participant studied three lists from each of the Head, Rime, and IP categories. The lists were randomly assigned to each participant, subject to two constraints. The first constraint was that every one of the nine critical lures was used exactly once for each participant. The second constraint was that the order of the lists was blocked into triplets so that each participant saw

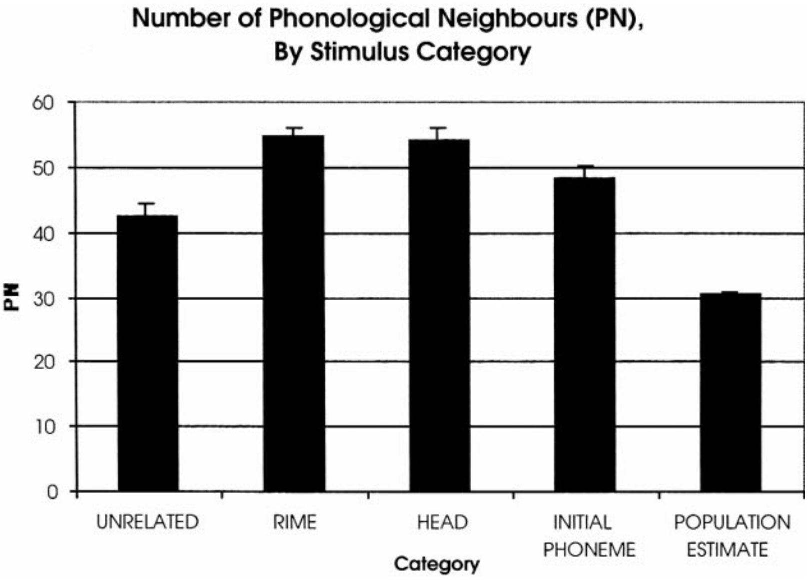

FIG. 1. Average number of phonological neighbors (PN), by stimulus category. For comparison, a population estimate has been added (see text for details). Bars are standard errors.

the same list category (Head, Rime, or IP) in the first, fourth, and seventh places; in the second, fifth, and eighth places; and in the third, sixth, and ninth places. Because of the random assignment for every participant, no participant saw exactly the same stimulus set as did any other participant.

Note that because all nine critical lures had all three list categories defined, there are 3! category orderings * 9! stimulus set orderings, for a total of 2,177,280 possible high-level orderings. There were many more possible stimulus-level orderings nested within each of these high-level orderings. The actual stimulus sets used were randomly drawn from this huge possibility space.

The composition of the test and study lists is illustrated in Fig. 2. As the figure shows, 6 of the 10 items in each study list were related items; that is, they were related to the critical lure defining the set for whichever one of the three relations (Head, Rime, or IP) was currently being used. The figure also shows that 4 unrelated items had no phonological overlap with that lure. The 4 unrelated stimuli were distributed roughly equally among the 6 related stimuli in such a way that each half of the study list consisted of 2 unrelated stimuli and 3 related stimuli.

Each test list also consisted of 10 items. It included 3 related and 2 unrelated items from the study list as well as 2 related and 2 unrelated items that did not appear on that list. These 9 words were ordered so that roughly half of each kind of stimulus was present in the first and second "half" (4- or 5-item sublist, randomly conjoined) of the list. These sublists were randomly appended to each other (i.e., half of the time the 4-item sublist was appended before the 5-item sublist, and half of the time it was appended

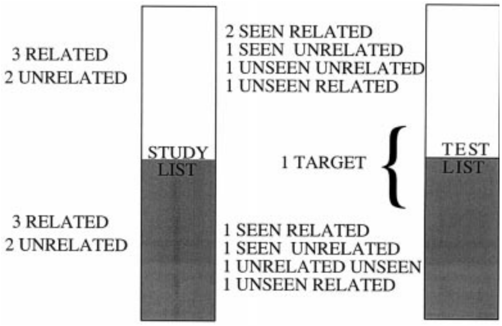

FIG. 2. Diagrammatic illustration of list structure for Experiment 1. See text for details.

TABLE 1

Examples of Two Stimulus Sets (study and test lists) from Experiment 1: A Head List for the Critical Lure *seal* and a Rime List for the Critical Lure *cone*

List	Stimulus	Target	Relation	Seen?	Stimulus	Target	Relation	Seen?
Study	seed	seal	Head	Seen	loan	cone	Tail	Seen
Study	big	seal	Unrelated	Seen	date	cone	Unrelated	Seen
Study	seize	seal	Head	Seen	file	cone	Unrelated	Seen
Study	gone	seal	Unrelated	Seen	shown	cone	Tail	Seen
Study	seethe	seal	Head	Seen	bone	cone	Tail	Seen
Study	seek	seal	Head	Seen	gauge	cone	Unrelated	Seen
Study	can	seal	Unrelated	Seen	hone	cone	Tail	Seen
Study	seat	seal	Head	Seen	phone	cone	Tail	Seen
Study	fan	seal	Unrelated	Seen	soup	cone	Unrelated	Seen
Study	scene	seal	Head	Seen	tone	cone	Tail	Seen
Test	seek	seal	Head	Seen	zone	cone	Tail	Unseen
Test	seam	seal	Head	Unseen	game	cone	Unrelated	Unseen
Test	seed	seal	Head	Seen	date	cone	Unrelated	Seen
Test	both	seal	Unrelated	Unseen	shown	cone	Tail	Seen
Test	big	seal	Unrelated	Seen	hawk	cone	Unrelated	Unseen
Test	seal	seal	Target	Unseen	cone	cone	Target	Unseen
Test	seep	seal	Head	Unseen	file	cone	Unrelated	Seen
Test	fan	seal	Unrelated	Seen	hone	cone	Tail	Seen
Test	seize	seal	Head	Seen	loan	cone	Tail	Seen
Test	den	seal	Unrelated	Unseen	sewn	cone	Tail	Unseen

after). The critical lure was randomly inserted in the middle triplet of the resulting 9-word list, ensuring that it appeared somewhere between the fourth and seventh place of the final 10-word test list.

Table 1 provides examples of two stimulus sets: a Head list for the critical lure *bake* and a Rime list for the critical lure *seal*. The first part of Appendix B contains a sample of an entire set of nine test and study lists that were shown to one participant for Experiment 1.

Results

We discarded words with reaction times of less than 250 ms (48 or 1.1% of all responses) or greater than 5,000 ms (16 or 0.4% of all responses).

The analysis takes two distinct paths. First, because all items were selected so that the critical lure could be presented in each of the three (Head, Rime, and IP) list conditions, we treat that lure as special and analyzed the differences between false memory rates for the critical lure as a function of list type. The results are presented in Table 2. Each participant's within-category average false alarm rates for the critical lures were entered into a one-way within-subjects analysis of variance (ANOVA). There are significant differences in the false memory rates as a function of list type, $F(2,96) = 3.37$, $p < .05$. This difference is attributable to a greater likelihood of false alarms to lures drawn from the Head (27.9% false recognition) and Rime (27.2% false recognition) conditions than to lures drawn from the IP condition (17.7% false recognition) ($p < .05$ by LSD test). The num-

TABLE 2

Probability of "Old" Responses as a Function of List Type for Experiment 1: Unmixed Lists

	Probability of saying "old"	
Category	Unpresented items	Presented Items
Unrelated	.09 (.01)	.73 (.03)
Head lures	.28 (.04)	N/A
Rime lures	.27 (.04)	N/A
IP lures	.18 (.03)	N/A
All Heads	.28 (.03)	.86 (.02)
All Rimes	.24 (.02)	.81 (.02)
All IPs	.19 (.02)	.81 (.02)

Note. Standard errors are in parentheses. N/A, not applicable; IPs, initial phonemes.

bers of false alarms made to words drawn from the Head and Rime categories did not differ from each other ($p > .05$).

The second analysis was undertaken because the first analysis treats critical lures as special within lists. However, in this experiment all of the related words in each test list are similar on precisely the same dimension as (and therefore functionally equivalent to) the critical lure. For example, the word *bake* is classified as a critical lure because it was used to define one set of words in each of the Head, Rime, IP, and Unrelated categories. However, the stimulus *bake* shares a relevant structural relation (in this example, a rime) with the unstudied words *rake* and *take*, which could also appear on the test list. Because of this identity of form, all items with the same relation to the study list as the critical lure should be expected to produce similar false memory rates. To examine this possibility, we combined the critical lures with their appropriate unpresented category items in the Head, Rime, and IP categories. The within-category average correct recognition rates for all unseen words (including Unrelated words) were entered into a within-subjects ANOVA. As would be expected, these data, presented in Table 2, mirror the lure results very closely. There is a significant difference among the four (Head, Rime, IP, and Unrelated) conditions, $F(3,144) = 22.44$, $p < .001$. Post hoc contrasts (LSD test) indicate that the words from the Head and Rime categories resulted in significantly more false memories than did the words from the Unrelated ($p < .0001$ in both cases), and IP (Head: $p < .005$; Rime: $p < .05$) categories, but there was no significant difference in the number of false memories between the Head and Rime conditions ($p = .15$). The IP condition resulted in significantly more false memories than the Unrelated condition ($p < .0001$).

In sum, all experimental manipulations resulted in increased false memory rates compared to the unrelated unseen words, with a two-phoneme overlap (in the Head and Rime conditions) resulting in more false memories than a single phoneme overlap (in the IP condition).

To assess the possibility that the results were related to phonological neighborhood size, we correlated the false memory rate for each word, averaged across all relation conditions and blocked by whether or not they were seen, with the size of that word's phonological neighborhood. For the seen words, the correlation was not significant ($R = -.05$, $p < .05$). However, among the unseen words, there was a significant positive correlation ($R = .23$, $p < .01$) between the size of a word's phonological neighborhood and the error rate. Participants were more likely to incorrectly judge that they had seen a word before if that word had a large phonological neighborhood.

Orthographic and phonological neighborhood sizes are significantly correlated ($R = .27$, $p < .01$ across all words in the stimuli set). The pattern of correlations of error rate with orthographic neighborhood size is similar to that with phonological neighborhood size. To ensure that our results were due only to phonological (and not only to orthographic) effects, we conducted two additional analyses.

In the first additional analysis, we looked at the orthographic overlap within our stimulus set. We computed an orthographic similarity measure of every stimulus string to its critical lure. We did so by computing the proportion of letters that the stimulus had in common with the lure. The algorithm for computing this proportion compared the stimulus string letter by letter with the critical lure, first from the back and then from the front, taking the average of these two counts. For example, if the stimulus is *shin* and the lure is *tin*, then the proportion of letters in common counting from the front is 0, whereas the proportion of letters in common counting from the back is 2/3. The average similarity count, therefore, is $(2/3 + 0)/2 = .33$. There are differences in this measure. Stimuli from the Rime category were significantly more orthographically similar to the critical lure than stimuli from the Head condition (.60 vs .49, respectively), $t(148) = 3.6$, $p < .001$. This overlap was not reflected in our findings (the higher orthographic overlap in the Rime condition did not produce a higher false memory rate), suggesting that orthographic overlap does not account for the false memory findings.

A more direct comparison may be obtained by comparing the amount of left-to-right overlap of stimuli from the Head category to their critical lures to the amount of right-to-left overlap of stimuli from the Rime category to their critical lures, that is, by comparing the different loci of overlap directly. This measure mirrors the global measure. The right-to-left overlap of words from the Rime category (average $= .64$) is significantly higher, $t(148) = 2.31$, $p < .05$, than the left-to-right overlap of words from the Head category (average $= .57$).

In a final analysis of the effect of orthographic overlap, we ordered all unseen stimuli from the Head and Rime categories by the average ([right-to-left + left-to-right]/2) orthographic overlap of the stimuli in those categories to their respective critical lures. We then conducted a median split. This gave us two groups that had phonological overlap held constant (because items from the Head and Rime categories are defined as having identical phonological overlap with their lures) but that differed in the amount of orthographic overlap. There was no significant difference in the number of false memories to critical lures reported in the high (73.1% correct) versus low (75.3% correct) orthographic overlap groups, $t(576) = 0.56$, $p > .05$. This result further buttresses the claim that the results cannot be due only to differences in orthographic overlap of the stimuli in the Head and Rime categories with their respective critical lures.

The above analyses focus only on the errors made to unpresented stimuli. There were also significant differences in the error (false negative) rate for presented items in each of the Unrelated, Head, Rime, and IP categories, $F(3, 144) = 8.86$, $p < .001$. The differences are roughly inversely proportional to the likelihood of false memory. Participants were more likely to incorrectly reject a seen Unrelated item (27%) than a seen item from one of the activated categories (Head: 14%; Rime: 19%; IP: 19%). Because the activated categories bias participants toward a "yes" response, as reflected in their increased false positive rate, this pattern is what is expected. Seen presented items in the activated (Head, Rime, and IP) categories "benefit" from an increased likelihood of rating even unseen items as seen in those categories, whereas seen Unrelated items do not receive any such benefit.

Discussion

This experiment addressed two questions. The first question was as follows: Does increased phonological overlap produce increased false memory rates? The most direct answer to this question is found in the contrast of false memory rates for words from the IP category to those from the Head category. Both of these categories contained words that overlapped with the lures at the onset stage of the words, thus maintaining location of overlap. They differed in that words from the IP category shared only the first phoneme with the lures, whereas words from the Head category shared the first two phonemes with the lures. The larger false alarm rates for words from the Head category shows that the extent of phonological overlap does make a difference. We return to this issue in the General Discussion at the end of this article.

We presented two analyses above that suggest that orthographic overlap alone could not account for the results of this experiment. However, those statistical analyses cannot rule out the possibility that some degree of orthographic overlap between seen words in the study lists and unseen words in the test lists played a role in the results. Previous work using an auditory lexical decision priming paradigm (Jakimik et al., 1985) showed that both orthographic and phonological overlap between a prime and a probe are required to get a priming effect.

The second question of interest was as follows: Do the Head and Rime overlap conditions produce different rates of false memories? The Marslen-Wilson cohort model of auditory word recognition would suggest that overlapping IPs play a greater role than do overlapping final phonemes in the organizational structure of the lexicon. That theory, therefore, would predict that words in the Head category should produce more false memories than words in the Rime category. However, Treiman and colleagues argued that in written word processing, the rime enjoys a special status. If that special status translates into an increased role in the organizational structure of the phonological storage or lexicon, then the words in the Rime category should be expected to produce the larger rate of false memories. Our findings do not strongly support a view that gives special status to heads or to rimes. We found no significant difference in the number of false memories to words from the Head or Rime category, although a nonsignificant ($p = .15$) trend toward increased memories for words from the Head category was observed.

Marslen-Wilson and colleagues reported that rime seems to play no role in the spread of activation (Marslen-Wilson, 1990; Marslen-Wilson & Zwitserlood, 1989) when measured via a priming effect. However, more recently a role for rime activation has been reported by other researchers (Andruski et al., 1994; Connine, Blasko, & Titone, 1993; Magnuson et al., 1999). The results reported here buttress the recent claim that there must exist some degree of rime-related spreading/shared activation because words from the Rime category resulted in significantly more false memories than did the control words from the Unrelated category. Words from the IP category also resulted in greater than control rates of false recognition, thus buttressing claims for a role for the IP in the spread of activation in the phonological system.

EXPERIMENT 2

Experiment 2 follows from our observation that the false memory rates were much lower in Experiment 1 than in similar studies conducted by Schacter et al. (1997); Shiffrin, Huber, and Marinelli (1995); and Sommers and Lewis (1999). We found a maximum of 27.9% false memories in the Head condition. Shiffrin et al. (1995) reported a false memory rate for phonological/orthographic lures as high as 38%. Schacter et al. (1997) reported false memory rates of 38% in Experiment 1 and 43% in Experiment 2. Sommers and Lewis (1999) reported false memory rates as high as 64%. The explanation for our relatively low false memory rates may be that our experiment differed from these others in important ways.

A methodological difference between our experiment and those of Schacter et al. and Shiffrin et al. was that both of these studies compiled individual study lists into one large study list that was followed by a single test. In our experiment, the study lists were centered on individual words, and corresponding test lists followed each of these pure lists. Differences in the magnitude of the false memory effects might merely indicate that longer lists are harder to remember than shorter lists. If this were true, then we should also see lower rates of veridical memory in those experiments. Schacter et al. (1997) reported average veridical rates between 73% and 83%, and Shiffrin et al. (1995) reported rates between 76% and 80%. By comparison, the veridical recognition rates in Experiment 1 ranged between a low of 73% and a high of 86%. Our experiment did produce the best performance. Because these veridical memory rates mirror the false memory rates, these results lend some credence to the hypothesis that false memory rates may reflect general task difficulty. Note, however, that the magnitude of the difference in veridical rates is not as large as that of the differences in false memory rates between our experiment and these others. There is likely an additional factor contributing to the difference in false memory rates.

The second difference between Experiment 1 and previous experiments is of more theoretical interest. The two previous experiments just described and Sommers and Lewis (1999) all used study lists containing a mix of heads and rimes of the critical lures. For example, in Schacter et al.’s (1997) experiment, the word *bright* was a critical lure in a list that contained the words *fright* and *brain*, and in Sommers and Lewis’s (1999) experiment, the word *cat* was a critical lure in a list that contained the words *cab* and *fat*. This mixing of words with overlapping heads and rimes in a single list produced a conjunction critical lure. Experiment 1 showed that both head and rime overlap resulted in more false memories than in control conditions. Other studies have shown that feature conjunctions produced greater false memories than did overlap of one feature (e.g., Reinitz, Lammers, & Cochran, 1992). Therefore, we decided to test the hypothesis that the differences in false memory rates between our study and these earlier ones reflect the presence of conjunction lists in those studies versus our use of pure lists.

Although an increase in false memories for critical lures in the conjunction condition would not be surprising, this effect would have several important implications for models of word recognition. The primary implications would be that subword phonological overlap plays an important role in the spread of activation. This would be consistent with a PDP account of phonological processing. Another implication would be that activation is maintained across more than one trial. This would be less consistent with a PDP account in which patterns of activation lead to the recognition of a single word.

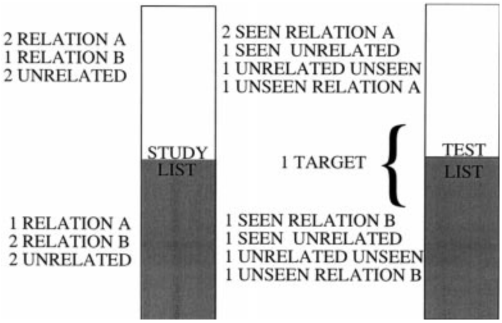

FIG. 3. Diagrammatic illustration of list structure for Experiment 2. To make the lists as similar in composition as possible to those of Experiment 1, a different number of stimuli related to the lure by each of the two (Head/Rime) relations had to be included in the study list. The role of each relation was randomized for each individual list that was constructed. In the diagram, therefore, Relation A and Relation B serve as variables to refer (randomly) to items from either the Head or Rime category. Note that participants saw exactly the same number of items related to the critical lure in Experiments 1 and 2. See text for details.

Method

Participants

A total of 49 native English-speaking undergraduates participated in this study to receive course credit.

Stimuli

The stimuli used in this experiment were drawn from the same pool of 300 stimuli used to construct the stimulus sets for Experiment 1. However, both the study and test lists differed from the first experiment’s lists. The main change is the manipulation of interest; words with overlapping heads and rimes occur in the same study list. The composition of the lists is illustrated in Fig. 3. For each of the nine critical lures, 3 words from the Head and Rime categories were mixed with 4 words from the Unrelated category. So far as possible, each of these three word types was represented equally often in the first and second halves of the list to form the study list. The result was a list of 10 words containing 2 words from the Unrelated category in each half and (randomly) either 1 or 2 words from each of the Head and Rime categories.

The test list of 10 words was constructed by including 3 of the seen related words. Because these 3 words were drawn from two categories (Head and Rime), each list randomly included 2 words from one of those categories and 1 word from the other category. The test list also contained 1 unseen word from each of the Head and Rime categories, 2 seen words from the Unrelated category, 2 unseen words from the Unrelated category, and the conjunction critical lure. As in Experiment 1, these words were organized so that roughly half of each word type was in each half of the list, with the Critical Lure inserted randomly between the fourth and seventh place of the final 10-word test list.

This procedure of creating study and test lists was repeated nine times for each participant until all nine critical lures had been used. The entire procedure was repeated until sufficient individual lists had been generated. Note that because we used only mixed lists of heads and rimes, all nine lists seen by participants in Experiment 2 instantiated the same relationship of critical lure to the study list. This contrasts with Experiment 1, in which participants saw three different relationships three times each.

The second part of Appendix B contains a sample of an entire set of nine test and study lists that were shown to one participant for Experiment 2.

Procedure

The experimental procedure was identical to that of Experiment 1. The same unanalyzed practice list was included in this experiment.

Results

The number of false memories produced by each participant was averaged within each stimulus category (Unrelated, Head, Rime, and Critical Lure, which has a unique character as a conjunction item in this experiment). The mean false memories for each condition are reported in Table 3. The differences evident in this table were examined in a within-subjects ANOVA and were statistically significant, $F(3,144) = 43.96$, $p < .001$.

LSD post hoc contrasts indicate that the Critical Lures resulted in significantly more false memories than did unstudied words from the Unrelated ($p < .00001$), Head ($p < .00001$), and Rime categories ($p < .00001$). Words from both the Head ($p < .0001$) and Rime categories ($p < .05$) resulted in significantly more false memories than did words from the Unrelated category. There were significantly ($p < .05$) more false memories to words in the Head category than in the Rime category.

The stimulus set and randomization procedures in this experiment were identical to those of Experiment 1. Therefore, there is no reason to expect a different average orthographic overlap between lures and stimuli in the two experiments. The false memory results (more false memories for words in the Head category than in the Rime category) are in the opposite direction of the orthographic overlap (larger average orthographic overlap with the Critical Lure in the Rime category than in the Head category). This dissociation lends further support to the claim that orthographic overlap cannot account for the findings.

TABLE 3

Probability of Saying "Old" as a Function of List Type for Experiment 2: Mixed Lists

	Probability of saying "old"	
Category	Unpresented items	Presented items
Unrelated	.10 (.02)	.75 (.03)
Head	.22 (.03)	.75 (.03)
Rime	.16 (.02)	.73 (.03)
Critical Lure	.40 (.03)	N/A

Note. Standard errors are in parentheses. N/A, not applicable.

Between-Experiment Analyses

To test the effect of the conjunction, we also compared the number of false memories generated for critical lures in Experiments 1 and 2. We made the comparison with a 2 (Experiments 1 or 2) × 4 (Head, Rime, Critical Lure, or Unrelated Category) between/within-subjects ANOVA. The results are graphed in Fig. 4. There was no significant difference in the number of false memories generated by the different experiments, $F(1, 96) = 0.16$, $p > .05$. The main effect of category was significant, as it had been in both experiments, $F(3, 288) = 49.3$, $p < .0001$. There was a significant Experiment × Category interaction, $F(3, 288) = 19.5$, $p < .0001$, due to an increase in false memories for the critical lures in Experiment 2 over those in Experiment 1.

In contrast to Experiment 1, there were no significant differences in Experiment 2 in the false negative rate to seen stimuli, $F(2,96) = 0.47$, $p > .05$. The false negative rate was higher in the activated categories than in Experiment 1 (Head: 25% compared to 14% in Experiment 1; Rime: 27% compared to 19% in Experiment 1) but was almost identical in the Unrelated category (25% compared to 27% in Experiment 1). Participants in Experiment 2 apparently were less confident in relying on a bias toward saying "yes" to all stimuli than were participants in Experiment 1. This may reflect the fact that Experiment 1, by activating only a single relationship of seen words to the critical lure in each list, included twice as many stimuli instantiating that relationship as did Experiment 2. In each Experiment 1 block, six seen words were related to the lure by either a Head, Rime, or IP relation. In Experiment 2, only three seen words in each block were related to the lure by each of a Head or Rime relationship. This difference in the number of seen words sharing the same relation may be reflected in differences in the false negative rates between the experiments.

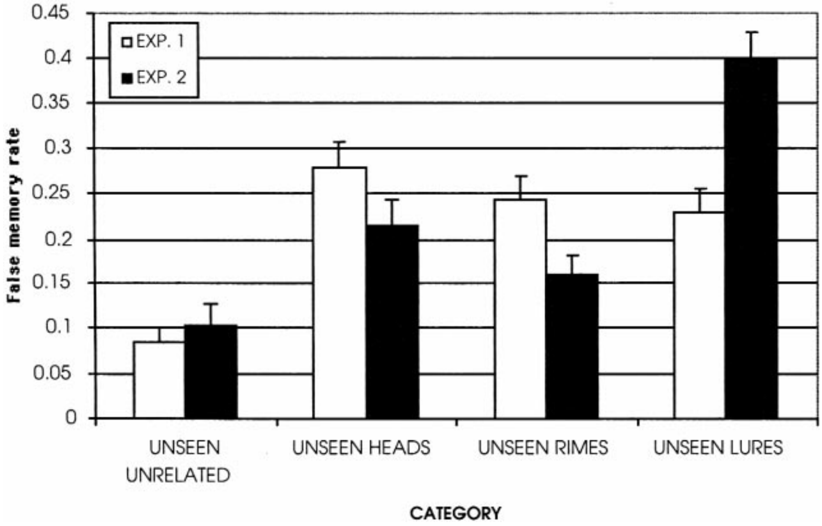

FIG. 4. False memory rates, by experiment. Bars are standard errors. The value for the lures in Experiment 1 is the average false memory rate of the Head and Rime lures. The value for the lures in Experiment 2 is the false memory rate for combined Head and Rime lures.

Discussion

We hypothesized that false memory rates would increase for the critical lures in Experiment 2 over Experiment 1 because they represent a conjunction of head and rime overlap. Our data are consistent with this notion. Although Experiments 1 and 2 had an identical formal structure with exactly the same number of items in the study list that were related to the critical lure (six in each), the false memory rate in Experiment 2 was 175% higher than that in Experiment 1.

Experiment 2 was designed to increase the phonological overlap between the studied words and the critical lure from that of Experiment 1. However, the form of the stimuli—with three phonemes each—introduces potential additional sources of information that may also be reflected in the results: the presence or absence of a unique phoneme and the degree of activation of phonemes in different positions. In Experiment 1, a critical lure in the Head or Rime condition had two highly activated phonemes (seen six times each in the study list) plus a single unique phoneme (i.e., one that had never been seen in that position in the study list). In Experiment 2, critical lures contained two partially activated phonemes (the first and last, each seen three times in the study list) plus a middle phoneme that was activated twice as much (seen six times because it appeared in both Head and Rime study words). In addition, those Experiment 2 lures contained no unique (unactivated) phonemes. This analysis implies that it might be too simplistic to think of Experiment 2 critical lure activation as being simply twice as much as Experiment 1 critical lure activation. Our results do not allow us to tease apart these potentially independent and/or differentially weighted sources of information that participants may bring to bear on a recognition decision.

GENERAL DISCUSSION

The experiments described here examined a number of issues in the visual word recognition literature and provided some insight into questions in the false memory literature. We first briefly consider the relevant false memory findings before discussing the more central findings with respect to theories of visual word recognition.

Issues in False Memory

We have based our examination of phonological activation on the assumption that spreading activation in the phonological system during the study phase results in increased familiarity for related unpresented items. We recognize, however, that because the items also appeared during the test phase, it is possible that we examined the spread of activation during the test phase as well as (or perhaps even rather than) during the study phase. We examined this possibility using an analysis of list placement and false memory rates for stimuli from Experiment 1. Recall that in that experiment, there is no functional difference between the critical lures, which can only appear in the fourth through seventh places of the test list, and unseen stimuli from the Head, Rime, and IP conditions, which may appear anywhere in the test list. Therefore, we are able to conduct an analysis of false memory rate to unseen stimuli by position of those stimuli in the test list. If false memories arise due to activation spread at test time, then we would expect that items further down in the list would result in more false memories than would items early in the list. We divided up the list into three positions—1st through 4th places (Early), 5th through 7th places (Middle), and 8th through 10th places (Late)—and calculated the false recognition rate in each category of word (Head, Rime, IP, and Unrelated) by place category. The results are shown in Table 4. False memories do increase with list position. There is a small increase (5% increase between Early and Late positions) for words from the Unrelated category. There are larger increases for words from the Head (12% increase from Early to Late), Rime (13% increase from Early to Late), and IP categories (17% increase). The increase was analyzed using a 3 (Early, Middle, or Late Position) × 4 (Head, Rime, IP, or Unrelated Category) within/between-subjects ANOVA. There is a main effect of list position, $F(2,130) = 5.5$, $p < .01$, but no significant interaction between category and list position, $F(6,390) = 0.27$, $p > .05$. These effects suggest that test list effects may be analogous to list length effects, making recognition errors of all kinds more likely.

This increasing false memory effect suggests that the uncertainty (or mistaken certainty) that is manifested in false memories can be effected in real time during the few seconds that elapse between presentations of words on the study list. However, not all of the false memory effect is attributable to this "acute" activation from the test list. There is a significant effect of studying the test list in the Early position only by four-way repeated measures ANOVA, $F(3,144) = 6.25$, $p < .001$. The false memory effect, therefore, also has a strong long-term component carried over from the study list, which is sufficient to clearly set the pattern that is deepened across all categories by the study list activation.

A related possibility is that the false memory rates also reflect an increase during the course of the experiment due to lingering sublexical activation from exposure to words seen earlier in the experiment. Because there are many fewer phonemes in the English language than there are words in this experiment, it is unavoidable that participants were exposed in later lists to phonemes or sublexical phoneme combinations that they had seen earlier. It is possible that this would be reflected in an increasing likelihood of making errors in later lists compared to earlier lists due to phonological activation carried over from exposure to earlier lists. To examine this, we collapsed Experiment 1 lures into their categories, as above. We then analyzed the false memory rates in each category by whether they appeared in the first, second, or third triplet of lists seen by each participant, using a 3 (List Third: first, second, or third) × 4 (Category:

TABLE 4

Probability of False Memory by Location in Test List in Experiment 1 for Unseen Stimuli Only

Position	Unrelated	Head	Rime	IP
Early (1st–4th)	.07 (.02)	.24 (.04)	.20 (.04)	.12 (.04)
Middle (5th–7th)	.08 (.02)	.30 (.05)	.26 (.05)	.18 (.04)
Late (8th–10th)	.12 (.02)	.36 (.04)	.33 (.04)	.29 (.04)

Note. Standard errors are in parentheses. IP, initial phoneme.

TABLE 5

Probability of Experiment 1 False Memory for Unseen Items by List Location

Third	Unrelated	Head	Rime	IP
First	.11 (.02)	.31 (.04)	.23 (.04)	.23 (.04)
Middle	.06 (.02)	.25 (.04)	.24 (.04)	.21 (.04)
Last	.08 (.02)	.27 (.04)	.26 (.04)	.14 (.04)

Note. Standard errors are in parentheses. IP, initial phoneme.

Head, Rime, IP, or Unrelated) between/within-subjects ANOVA. The results are shown in Table 5. There was no main effect of list-third, $F(2, 144) = 0.06$, $p > .05$. Furthermore, there was no List Third × Category interaction, $F(6, 432) = 0.88$, $p > .05$. These results suggest that there was no false memory effect attributable to list position.

Another issue of relevance to the false memory literature is the question of whether increased overlap results in increased false memory rates. Wallace and colleagues showed that increased phonological overlap results in increased false memory rates. We replicate that finding here with a more stringently controlled test. This suggests to us that false memory rates are a useful index of the relative similarity of a critical lure to items in a study list. Our finding that false memories rise in concert with the overlap of the critical lure to the study list provides some support for our assumption that we are, in fact, obtaining information about what features are important in decisions about phonological similarity.

Issues in Visual Word Recognition

Our primary goal was to establish the characteristics that guide the spread of activation among phonological cohorts during visual word processing. In the introduction, we cited evidence in support of the IP, head, and rime all playing a role in phonological activation. Our results are consistent with these findings given that we found significant effects of all three overlap types on false memory rates. Other data from this study (i.e., the difference in false memory rates for words from the single-phoneme overlap IP category as compared to the double-phoneme overlap Head and Rime categories) indicate that the amount of overlap is important. However, the results of Experiment 2 suggest to us that the head of a CVC is the best predictor of activation spread to a lure. This finding supports the special status of the head over the rime in phonological lexical arrangement. The conclusion that the head plays a special role in spreading activation during phonological processing is based on the increase of false alarms for words in the Head category over words from the Rime category in Experiment 2. A similar nonsignificant trend of increased false memories for Head-activated lures was seen in Experiment 1 ($p = .15$ in post hoc comparisons of the greater unseen Head false memory rates to the lesser unseen Rime false memory rates).

Part of the advantage for heads may arise because the head contains the IP—a special part of the word. This position is consistent with the claim in Treiman et al. (1995) regarding the special status of the IP. However, in Treiman et al.'s argument, the IP has special status because CVC words are parsed into IP–rime units, precluding a role for the head in processing of a printed word. To the extent that we show a distinct increase in false memories in one experiment for words from the Head category over words from the Rime category and greater false memories for words from the Head category than for words from the IP category, the special status of the IP cannot be due only to an IP–rime parsing of the word. Rather, it appears as though activation spreads in a serial manner, with more emphasis on the beginning of the word than on the end. By the time a word is read (i.e., the end of the word has been processed), activation is likely to have settled on a word set, with the result that the shared activation is reduced for final consonants relative to initial consonants.

The strong conjunction effect in Experiment 2 demonstrates that heads are not the only feature by which activation may spread. False memories for lures increased dramatically when both heads and rimes appeared on the same list, producing a phonological conjunction. We argued that this conjunction increased the activation of the unseen critical lure and produced much higher false alarms for those words than for words in the other conditions. The findings in Experiment 2, therefore, are consistent with previous work with nonwords (e.g., Reinitz et al., 1992). The conjunction effect in Experiment 2 suggests that the memory representation for linguistic items must exist in units smaller than the whole word. Input from these smaller units can spread to related items. The findings that we report also suggest that activation received by these units remains in the system for several minutes and is subject to additional boosts when other related items are presented.

It may be argued that we have not examined the spread of activation within the phonological lexicon at all given that we presented orthographic items. Perhaps the findings we report may best be considered an assessment of the spread of activation within the orthographic lexicon (cf. Coltheart et al., 1993) or layer (cf. Plaut et al., 1996) of the word recognition system. We counter that argument with our orthographic analysis of the items in these experiments. Overall, heads have more effect than do rimes or IPs in activating entries or producing familiarity. This finding, which is consistent with prior evidence (e.g., Wallace et al., 1995), cannot be attributed to orthographic overlap. In our stimuli, words that share a head with a critical lure have less orthographic overlap with that lure than do words that share a rime.

False Memories and Word Recognition Models

We now consider these findings within the context of the two models of word recognition outlined in the introduction, namely the DRC model (Coltheart et al., 1993) and the PDP model (Plaut et al., 1996).

The DRC model of word reading assumes that lexical entries are represented at a whole-word level. Under this view, whole-word representations receive spreading activation from word entries that share phonological features, resulting in increased familiarity during testing. For example, the entry *cat* would receive activation spreading from all whole-word neighbors ending in *at* as well as from all neighbors beginning with *ca*. However, the increased false memory rate for the critical lures in Experiment 2 over those in Experiment 1 is difficult to reconcile with such a whole-word view of the phonological lexicon. That finding seems necessarily to implicate subword spreading of activation. A strictly whole-word view does not allow for unequal activation contributions of same-length subword elements because it does not allow for subword activation at all. Whole-word models, therefore, predict that six CVC words ending in *at* should activate the word *cat* as much as three CVC words ending with *at* and three CVC words beginning with *ca*. There should be no distinction between activation due to overlapping heads and activation due to an equal amount of overlapping heads and rimes. However, this is not what the data show; there was a marked increase in false memory rates for critical lures in the conjunction condition over the pure conditions.

PDP models of phonological activation may provide a better account for the current findings because they do not assume that activation spreads to and from whole words. This view can easily accommodate the finding that the phonological entries for rimes are activated separately from phonological entries for heads. When both the rime and the head of a critical lure are activated during study (as in Experiment 2), the critical lure is also activated, resulting in the increased sense of familiarity (e.g., Brown et al., in press) that leads to a false memory. However, in this view, the entry for a rime must remain activated until the entry for the head becomes active in order for the conjunction of the two to become activated at an increased rate. This suggests that activation of one item must remain despite activation of a second item.

Although the possibility of maintained activation exists in current PDP instantiations (for a discussion of semantic priming across items, see Plaut, 1995), it does not fit comfortably within a PDP account that relies on the identification of *patterns* of activation for reading. For example, in models that assume recognition of patterns of activation, the (phonemic) entries for *ca* and *at* would be activated to indicate that the word *cat* is being considered. Recognition of the word *cat* depends on the pattern of activation and not simply on the activation of individual entries. When *bad* is presented, the *ba* and *ad* entries are activated. If *ca* and *at* entries from the word *cat* remain active when *ba* and *ad* are being considered, then the overall pattern of activation is muddied. The activation pattern includes *ca*, *at*, *ba*, and *ad*, resulting in an incorrect (and, in this case, an unrecognizable) pattern. However, it is precisely this simultaneous activation that would lead to the blend or conjunction that, in this example, leads to later increased familiarity for a related item such as *bat*. Plaut (1995) was able to show that such carryover effects can occur in semantic priming. The same effect may be possible with respect to phonology. However, the precise mechanisms by which this could occur are unspecified in the current descriptions of the PDP model.

CONCLUSION

We have examined a series of conditions assumed to reflect levels of activation in the phonological layer (Plaut et al., 1996) or the phonological lexicon (Coltheart et al., 1993). We have shown that any amount of phonological overlap appears to result in some feeling of familiarity for an unpresented word. We have also shown that for CVCs, the head predicts spread/shared activation better than does the IP or the rime. The results suggest that lexical activation spreads by both whole-word and subword units. We argue that the findings do not fit comfortably within current instantiations of either the DRC or PDP model of word recognition. We will take these findings as a guide for future examinations of the organizational properties of the phonological lexicon. Our current view is that activation is sustained across several presentations and that it spreads at both subword and whole-word levels.

Our findings imply that subword phonological components may be active for some time. This could create a problem for text comprehension if it produced a number of conjunction errors. However, the phonological/orthographic complexity of text or discourse combined with the constraints of semantics should make such errors unlikely. The notion of sustained activation is consistent with the evidence that people do maintain verbatim information for some time and points to the mechanism that supports sound-based poetic devices such as rhyme and alliteration.

APPENDIX A

All Stimuli

Stimulus	Lure	Category
bake	bake	Critical Lure
fake	bake	Rime
lake	bake	Rime
make	bake	Rime
rake	bake	Rime
sake	bake	Rime
shake	bake	Rime
take	bake	Rime
wake	bake	Rime
babe	bake	Head
bail	bake	Head
bait	bake	Head
bane	bake	Head
base	bake	Head
beige	bake	Head
bade	bake	Head
bathe	bake	Head
bite	bake	IP
beach	bake	IP
beat	bake	IP
boat	bake	IP
bull	bake	IP
bush	bake	IP
bath	bake	IP
bell	bake	IP
cash	bake	Unrelated
chip	bake	Unrelated
seal	bake	Unrelated
dune	bake	Unrelated
fuzz	bake	Unrelated
doll	bake	Unrelated
fool	bake	Unrelated
kiss	bake	Unrelated
knife	bake	Unrelated
laugh	bake	Unrelated
rap	rap	Critical Lure
cap	rap	Rime
chap	rap	Rime

APPENDIX A—*Continued*

All Stimuli

Stimulus	Lure	Category
gap	rap	Rime
lap	rap	Rime
map	rap	Rime
nap	rap	Rime
sap	rap	Rime
tap	rap	Rime
yap	rap	Rime
zap	rap	Rime
rack	rap	Head
rag	rap	Head
ram	rap	Head
ran	rap	Head
wrath	rap	Head
rash	rap	Head
rat	rap	Head
rang	rap	Head
roll	rap	IP
roof	rap	IP
rare	rap	IP
rot	rap	IP
rhyme	rap	IP
rich	rap	IP
run	rap	IP
rice	rap	IP
site	rap	Unrelated
soar	rap	Unrelated
toss	rap	Unrelated
touch	rap	Unrelated
join	rap	Unrelated
goat	rap	Unrelated
foul	rap	Unrelated
cube	rap	Unrelated
bomb	rap	Unrelated
cone	cone	Critical Lure
bone	cone	Rime
hone	cone	Rime
known	cone	Rime
loan	cone	Rime
zone	cone	Rime
moan	cone	Rime
tone	cone	Rime
phone	cone	Rime
sewn	cone	Rime
shown	cone	Rime
coach	cone	Head
coal	cone	Head
coat	cone	Head
code	cone	Head
coke	cone	Head
comb	cone	Head
cope	cone	Head
cove	cone	Head
cage	cone	IP
catch	cone	IP
call	cone	IP
cape	cone	IP
care	cone	IP
case	cone	IP
cause	cone	IP
cave	cone	IP
deaf	cone	Unrelated
dash	cone	Unrelated
date	cone	Unrelated
soup	cone	Unrelated
file	cone	Unrelated
game	cone	Unrelated
gauge	cone	Unrelated
haul	cone	Unrelated
hawk	cone	Unrelated
rail	rail	Critical Lure
bail	rail	Rime
gail	rail	Rime
tail	rail	Rime
hail	rail	Rime
jail	rail	Rime
nail	rail	Rime
mail	rail	Rime
sail	rail	Rime
shale	rail	Rime
race	rail	Head
rage	rail	Head
raid	rail	Head
rain	rail	Head
raise	rail	Head
rake	rail	Head
rate	rail	Head
rave	rail	Head
rib	rail	IP
rub	rail	IP
roam	rail	IP
roar	rail	IP
rock	rail	IP
root	rail	IP
rush	rail	IP
rude	rail	IP
scent	rail	Unrelated
sip	rail	Unrelated
term	rail	Unrelated
thumb	rail	Unrelated
tide	rail	Unrelated
pick	rail	Unrelated
sat	rail	Unrelated
yolk	rail	Unrelated
tote	rail	Unrelated
soak	rail	Unrelated
roll	roll	Critical Lure

APPENDIX A—*Continued*

All Stimuli

Stimulus	Lure	Category
bowl	roll	Rime
coal	roll	Rime
dole	roll	Rime
foal	roll	Rime
goal	roll	Rime
hole	roll	Rime
mole	roll	Rime
soul	roll	Rime
pole	roll	Rime
roan	roll	Head
robe	roll	Head
rode	roll	Head
rogue	roll	Head
rope	roll	Head
rose	roll	Head
rote	roll	Head
rove	roll	Head
rum	roll	IP
rug	roll	IP
rip	roll	IP
rut	roll	IP
red	roll	IP
reap	roll	IP
rim	roll	IP
rig	roll	IP
ban	roll	Unrelated
bin	roll	Unrelated
beg	roll	Unrelated
cane	roll	Unrelated
chin	roll	Unrelated
lathe	roll	Unrelated
mash	roll	Unrelated
wash	roll	Unrelated
seal	seal	Critical Lure
feel	seal	Rime
deal	seal	Rime
reel	seal	Rime
peel	seal	Rime
heal	seal	Rime
meal	seal	Rime
wheel	seal	Rime
keel	seal	Rime
scene	seal	Head
seam	seal	Head
seize	seal	Head
seat	seal	Head
seed	seal	Head
seek	seal	Head
siege	seal	Head
seep	seal	Head
safe	seal	IP
sin	seal	IP
sad	seal	IP
sash	seal	IP
sage	seal	IP
sane	seal	IP
sing	seal	IP
sit	seal	IP
big	seal	Unrelated
both	seal	Unrelated
can	seal	Unrelated
chose	seal	Unrelated
kook	seal	Unrelated
den	seal	Unrelated
fan	seal	Unrelated
gone	seal	Unrelated
will	will	Critical Lure
bill	will	Rime
chill	will	Rime
dill	will	Rime
fill	will	Rime
gill	will	Rime
kill	will	Rime
mill	will	Rime
sill	will	Rime
which	will	Head
wiff	will	Head
whim	will	Head
wit	will	Head
whiz	will	Head
whip	will	Head
wick	will	Head
wig	will	Head
wail	will	IP
wan	will	IP
wheat	will	IP
weep	will	IP
wipe	will	IP
wag	will	IP
watt	will	IP
wing	will	IP
bought	will	Unrelated
bag	will	Unrelated
chase	will	Unrelated
cop	will	Unrelated
hot	will	Unrelated
keen	will	Unrelated
lag	will	Unrelated
mat	will	Unrelated
pack	pack	Critical Lure
back	pack	Rime
hack	pack	Rime
jack	pack	Rime
knack	pack	Rime

APPENDIX A—*Continued*

All Stimuli

Stimulus	Lure	Category	Stimulus	Lure	Category
lack	pack	Rime	beak	leak	Rime
shack	pack	Rime	meek	leak	Rime
sack	pack	Rime	peak	leak	Rime
wack	pack	Rime	reek	leak	Rime
pad	pack	Head	seek	leak	Rime
pal	pack	Head	weak	leak	Rime
pan	pack	Head	geek	leak	Rime
pap	pack	Head	leach	leak	Head
pat	pack	Head	lead	leak	Head
pass	pack	Head	leaf	leak	Head
patch	pack	Head	league	leak	Head
path	pack	Head	lean	leak	Head
pout	pack	IP	leap	leak	Head
ping	pack	IP	leave	leak	Head
pale	pack	IP	leash	leak	Head
peet	pack	IP	lad	leak	IP
pot	pack	IP	lash	leak	IP
pit	pack	IP	loam	leak	IP
peeve	pack	IP	leg	leak	IP
peg	pack	IP	log	leak	IP
beef	pack	Unrelated	lob	leak	IP
boil	pack	Unrelated	lug	leak	IP
came	pack	Unrelated	lout	leak	IP
check	pack	Unrelated	zoom	leak	Unrelated
dig	pack	Unrelated	white	leak	Unrelated
fail	pack	Unrelated	tad	leak	Unrelated
gain	pack	Unrelated	soot	leak	Unrelated
hag	pack	Unrelated	sag	leak	Unrelated
leak	leak	Critical Lure	ring	leak	Unrelated
cheek	leak	Rime	fun	leak	Unrelated
			fog	leak	Unrelated

APPENDIX B

Sample Set of Test Stimuli Seen by One Participant

Experiment 1

Block	Stimulus	Target	Relation	Seen?	List type
1A	gail	rail	Rime	Seen	Study
1A	tide	rail	Unrelated	Seen	Study
1A	scent	rail	Unrelated	Seen	Study
1A	nail	rail	Rime	Seen	Study
1A	pick	rail	Unrelated	Seen	Study
1A	ball	rail	Rime	Seen	Study
1A	sail	rail	Rime	Seen	Study
1A	mail	rail	Rime	Seen	Study
1A	thumb	rail	Unrelated	Seen	Study
1A	jail	rail	Rime	Seen	Study
1A	tide	rail	Unrelated	Seen	Test
1A	sat	rail	Unrelated	Unseen	Test
1A	gail	rail	Rime	Seen	Test

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 1

Block	Stimulus	Target	Relation	Seen?	List type
1A	rall	rail	Target	Unseen	Test
1A	tail	rail	Rime	Unseen	Test
1A	shale	rail	Rime	Unseen	Test
1A	bail	rail	Rime	Seen	Test
1A	scent	rail	Unrelated	Seen	Test
1A	nail	rail	Rime	Seen	Test
1A	term	rail	Unrelated	Unseen	Test
1B	chase	will	Unrelated	Seen	Study
1B	keen	will	Unrelated	Seen	Study
1B	wail	will	IP	Seen	Study
1B	wing	will	IP	Seen	Study
1B	cop	will	Unrelated	Seen	Study
1B	wan	will	IP	Seen	Study
1B	weep	will	IP	Seen	Study
1B	watt	will	IP	Seen	Study
1B	lag	will	Unrelated	Seen	Study
1B	wheat	will	IP	Seen	Study
1B	weep	will	IP	Seen	Test
1B	bag	will	Unrelated	Unseen	Test
1B	wipe	will	IP	Unseen	Test
1B	wing	will	IP	Seen	Test
1B	keen	will	Unrelated	Seen	Test
1B	will	will	Target	Unseen	Test
1B	hot	will	Unrelated	Unseen	Test
1B	wail	will	IP	Seen	Test
1B	wag	will	IP	Unseen	Test
1B	chase	will	Unrelated	Seen	Test
1C	ring	leak	Unrelated	Seen	Study
1C	leave	leak	Head	Seen	Study
1C	league	leak	Head	Seen	Study
1C	tad	leak	Unrelated	Seen	Study
1C	lead	leak	Head	Seen	Study
1C	leaf	leak	Head	Seen	Study
1C	soot	leak	Unrelated	Seen	Study
1C	leash	leak	Head	Seen	Study
1C	fun	leak	Unrelated	Seen	Study
1C	lean	leak	Head	Seen	Study
1C	leach	leak	Head	Unseen	Test
1C	fog	leak	Unrelated	Unseen	Test
1C	leave	leak	Head	Seen	Test
1C	fun	leak	Unrelated	Seen	Test
1C	leak	leak	Target	Unseen	Test
1C	zoom	leak	Unrelated	Unseen	Test
1C	leap	leak	Head	Unseen	Test
1C	league	leak	Head	Seen	Test
1C	leaf	leak	Head	Seen	Test
1C	ring	leak	Unrelated	Seen	Test
2A	ban	roll	Unrelated	Seen	Study
2A	pole	roll	Rime	Seen	Study
2A	lathe	roll	Unrelated	Seen	Study
2A	bowl	roll	Rime	Seen	Study
2A	doze	roll	Rime	Seen	Study

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 1

Block	Stimulus	Target	Relation	Seen?	List type
2A	bake	roll	Unrelated	Seen	Study
2A	hole	roll	Rime	Seen	Study
2A	mole	roll	Rime	Seen	Study
2A	cane	roll	Unrelated	Seen	Study
2A	dole	roll	Rime	Seen	Study
2A	mash	roll	Unrelated	Unseen	Test
2A	lathe	roll	Unrelated	Seen	Test
2A	coal	roll	Rime	Unseen	Test
2A	roll	roll	Target	Unseen	Test
2A	pole	roll	Rime	Seen	Test
2A	bowl	roll	Rime	Seen	Test
2A	wash	roll	Unrelated	Unseen	Test
2A	soul	roll	Rime	Unseen	Test
2A	ban	roll	Unrelated	Seen	Test
2A	hole	roll	Rime	Seen	Test
2B	beach	bake	IP	Seen	Study
2B	chip	bake	Unrelated	Seen	Study
2B	laugh	bake	Unrelated	Seen	Study
2B	bush	bake	IP	Seen	Study
2B	doll	bake	Unrelated	Seen	Study
2B	bite	bake	IP	Seen	Study
2B	bath	bake	IP	Seen	Study
2B	bull	bake	IP	Seen	Study
2B	bell	bake	IP	Seen	Study
2B	kiss	bake	Unrelated	Seen	Study
2B	boat	bake	IP	Unseen	Test
2B	fool	bake	Unrelated	Unseen	Test
2B	bush	bake	IP	Seen	Test
2B	bake	bake	Target	Unseen	Test
2B	laugh	bake	Unrelated	Seen	Test
2B	beat	bake	IP	Unseen	Test
2B	knife	bake	Unrelated	Unseen	Test
2B	chip	bake	Unrelated	Seen	Test
2B	beach	bake	IP	Seen	Test
2B	bite	bake	IP	Seen	Test
2C	pal	pack	Head	Seen	Study
2C	dig	pack	Unrelated	Seen	Study
2C	pad	pack	Head	Seen	Study
2C	hag	pack	Unrelated	Seen	Study
2C	fail	pack	Unrelated	Seen	Study
2C	pap	pack	Head	Seen	Study
2C	patch	pack	Head	Seen	Study
2C	beef	pack	Unrelated	Seen	Study
2C	pass	pack	Head	Seen	Study
2C	path	pack	Head	Seen	Study
2C	pat	pack	Head	Unseen	Test
2C	check	pack	Unrelated	Unseen	Test
2C	pad	pack	Head	Seen	Test
2C	pack	pack	Target	Unseen	Test
2C	dig	pack	Unrelated	Seen	Test
2C	pal	pack	Head	Seen	Test
2C	pan	pack	Head	Unseen	Test

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 1

Block	Stimulus	Target	Relation	Seen?	List type
2C	patch	pack	Head	Seen	Test
2C	hag	pack	Unrelated	Seen	Test
2C	gain	pack	Unrelated	Unseen	Test
3A	loan	cone	Rime	Seen	Study
3A	date	cone	Unrelated	Seen	Study
3A	file	cone	Unrelated	Seen	Study
3A	shown	cone	Rime	Seen	Study
3A	bone	cone	Rime	Seen	Study
3A	gauge	cone	Unrelated	Seen	Study
3A	hone	cone	Rime	Seen	Study
3A	phone	cone	Rime	Seen	Study
3A	soup	cone	Unrelated	Seen	Study
3A	tone	cone	Rime	Seen	Study
3A	zone	cone	Rime	Unseen	Test
3A	game	cone	Unrelated	Unseen	Test
3A	date	cone	Unrelated	Seen	Test
3A	shown	cone	Rime	Seen	Test
3A	hawk	cone	Unrelated	Unseen	Test
3A	cone	cone	Target	Unseen	Test
3A	file	cone	Unrelated	Seen	Test
3A	hone	cone	Rime	Seen	Test
3A	loan	cone	Rime	Seen	Test
3A	sewn	cone	Rime	Unseen	Test
3B	sing	seal	IP	Seen	Study
3B	gone	seal	Unrelated	Seen	Study
3B	sad	seal	IP	Seen	Study
3B	sit	seal	IP	Seen	Study
3B	big	seal	Unrelated	Seen	Study
3B	kook	seal	Unrelated	Seen	Study
3B	sin	seal	IP	Seen	Study
3B	chose	seal	Unrelated	Seen	Study
3B	sage	seal	IP	Seen	Study
3B	safe	seal	IP	Seen	Study
3B	den	seal	Unrelated	Unseen	Test
3B	sing	seal	IP	Seen	Test
3B	sane	seal	IP	Unseen	Test
3B	seal	seal	Target	Unseen	Test
3B	big	seal	Unrelated	Seen	Test
3B	sash	seal	IP	Unseen	Test
3B	sad	seal	IP	Seen	Test
3B	gone	seal	Unrelated	Seen	Test
3B	can	seal	Unrelated	Unseen	Test
3B	sit	seal	IP	Seen	Test
3C	rat	wrap	Head	Seen	Study
3C	site	wrap	Unrelated	Seen	Study
3C	rash	wrap	Head	Seen	Study
3C	wrath	wrap	Head	Seen	Study
3C	bomb	wrap	Unrelated	Seen	Study
3C	rag	wrap	Head	Seen	Study
3C	join	wrap	Unrelated	Seen	Study
3C	cube	wrap	Unrelated	Seen	Study
3C	rack	wrap	Head	Seen	Study

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 1

Block	Stimulus	Target	Relation	Seen?	List type
3C	ram	wrap	Head	Seen	Study
3C	soar	wrap	Unrelated	Unseen	Test
3C	ran	wrap	Head	Unseen	Test
3C	rash	wrap	Head	Seen	Test
3C	bomb	wrap	Unrelated	Seen	Test
3C	site	wrap	Unrelated	Seen	Test
3C	wrap	wrap	Target	Unseen	Test
3C	toss	wrap	Unrelated	Unseen	Test
3C	rang	wrap	Head	Unseen	Test
3C	rat	wrap	Head	Seen	Test
3C	rag	wrap	Head	Seen	Test

Experiment 2

Block	Stimulus	Target	Relation	Seen?	List type
1	bin	roll	Unrelated	Seen	Study
1	rove	roll	Head	Seen	Study
1	rose	roll	Head	Seen	Study
1	cane	roll	Unrelated	Seen	Study
1	bowl	roll	Rime	Seen	Study
1	soul	roll	Rime	Seen	Study
1	roan	roll	Head	Seen	Study
1	beg	roll	Unrelated	Seen	Study
1	goal	roll	Rime	Seen	Study
1	ban	roll	Unrelated	Seen	Study
1	goal	roll	Rime	Seen	Test
1	chin	roll	Unrelated	Seen	Test
1	coal	roll	Rime	Unseen	Test
1	cane	roll	Unrelated	Seen	Test
1	mash	roll	Unrelated	Unseen	Test
1	roll	roll	Target	Unseen	Test
1	rode	roll	Head	Unseen	Test
1	beg	roll	Unrelated	Seen	Test
1	soul	roll	Rime	Seen	Test
1	rose	roll	Head	Seen	Test
2	coal	cone	Head	Seen	Study
2	sewn	cone	Rime	Seen	Study
2	dash	cone	Unrelated	Seen	Study
2	hawk	cone	Unrelated	Seen	Study
2	date	cone	Unrelated	Seen	Study
2	loan	cone	Rime	Seen	Study
2	file	cone	Unrelated	Seen	Study
2	tone	cone	Rime	Seen	Study
2	coat	cone	Head	Seen	Study
2	comb	cone	Head	Seen	Study
2	tone	cone	Rime	Seen	Test
2	soup	cone	Unrelated	Unseen	Test
2	code	cone	Head	Unseen	Test
2	coal	cone	Head	Seen	Test
2	hawk	cone	Unrelated	Seen	Test
2	cone	cone	Target	Unseen	Test

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 2

Block	Stimulus	Target	Relation	Seen?	List type
2	file	cone	Unrelated	Seen	Test
2	game	cone	Unrelated	Unseen	Test
2	loan	cone	Rime	Seen	Test
2	zone	cone	Rime	Unseen	Test
3	sill	will	Rime	Seen	Study
3	which	will	Head	Seen	Study
3	bill	will	Rime	Seen	Study
3	lag	will	Unrelated	Seen	Study
3	whiz	will	Head	Seen	Study
3	bag	will	Unrelated	Seen	Study
3	hot	will	Unrelated	Seen	Study
3	whim	will	Head	Seen	Study
3	chase	will	Unrelated	Seen	Study
3	kill	will	Rime	Seen	Study
3	wick	will	Head	Unseen	Test
3	which	will	Head	Seen	Test
3	bought	will	Unrelated	Unseen	Test
3	bag	will	Unrelated	Seen	Test
3	kill	will	Rime	Seen	Test
3	will	will	Target	Unseen	Test
3	hot	will	Unrelated	Seen	Test
3	cop	will	Unrelated	Unseen	Test
3	whiz	will	Head	Seen	Test
3	dill	will	Rime	Unseen	Test
4	jack	pack	Rime	Seen	Study
4	pass	pack	Head	Seen	Study
4	beef	pack	Unrelated	Seen	Study
4	hag	pack	Unrelated	Seen	Study
4	pan	pack	Head	Seen	Study
4	shack	pack	Rime	Seen	Study
4	boil	pack	Unrelated	Seen	Study
4	gain	pack	Unrelated	Seen	Study
4	knack	pack	Rime	Seen	Study
4	path	pack	Head	Seen	Study
4	hack	pack	Rime	Unseen	Test
4	fail	pack	Unrelated	Unseen	Test
4	path	pack	Head	Seen	Test
4	hag	pack	Unrelated	Seen	Test
4	pap	pack	Head	Unseen	Test
4	came	pack	Unrelated	Unseen	Test
4	pack	pack	Target	Unseen	Test
4	boil	pack	Unrelated	Seen	Test
4	jack	pack	Rime	Seen	Test
4	pan	pack	Head	Seen	Test
4	bade	bake	Head	Seen	Study
5	shake	bake	Rime	Seen	Study
5	cash	bake	Unrelated	Seen	Study
5	chip	bake	Unrelated	Seen	Study
5	laugh	bake	Unrelated	Seen	Study
5	make	bake	Rime	Seen	Study
5	bane	bake	Head	Seen	Study
5	fuzz	bake	Unrelated	Seen	Study

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 2

Block	Stimulus	Target	Relation	Seen?	List type
5	bait	bake	Head	Seen	Study
5	lake	bake	Rime	Seen	Study
5	lake	bake	Rime	Seen	Test
5	dune	bake	Unrelated	Unseen	Test
5	babe	bake	Head	Unseen	Test
5	bade	bake	Head	Seen	Test
5	fuzz	bake	Unrelated	Seen	Test
5	shake	bake	Rime	Seen	Test
5	bake	bake	Target	Unseen	Test
5	rake	bake	Rime	Unseen	Test
5	fool	bake	Unrelated	Unseen	Test
5	chip	bake	Unrelated	Seen	Test
6	cube	rap	Unrelated	Seen	Study
6	zap	rap	Rime	Seen	Study
6	rash	rap	Head	Seen	Study
6	toss	rap	Unrelated	Seen	Study
6	goat	rap	Unrelated	Seen	Study
6	cap	rap	Rime	Seen	Study
6	rat	rap	Head	Seen	Study
6	bomb	rap	Unrelated	Seen	Study
6	ram	rap	Head	Seen	Study
6	nap	rap	Rime	Seen	Study
6	site	rap	Unrelated	Unseen	Test
6	toss	rap	Unrelated	Seen	Test
6	rack	rap	Head	Unseen	Test
6	nap	rap	Rime	Seen	Test
6	rash	rap	Head	Seen	Test
6	goat	rap	Unrelated	Seen	Test
6	rap	rap	Target	Unseen	Test
6	sap	rap	Rime	Unseen	Test
6	rat	rap	Head	Seen	Test
6	soar	rap	Unrelated	Unseen	Test
7	heal	seal	Rime	Seen	Study
7	both	seal	Unrelated	Seen	Study
7	seat	seal	Head	Seen	Study
7	kook	seal	Unrelated	Seen	Study
7	feel	seal	Rime	Seen	Study
7	seize	seal	Head	Seen	Study
7	wheel	seal	Rime	Seen	Study
7	scene	seal	Head	Seen	Study
7	chose	seal	Unrelated	Seen	Study
7	can	seal	Unrelated	Seen	Study
7	kook	seal	Unrelated	Seen	Test
7	keel	seal	Rime	Unseen	Test
7	seize	seal	Head	Seen	Test
7	gone	seal	Unrelated	Unseen	Test
7	seal	seal	Target	Unseen	Test
7	chose	seal	Unrelated	Seen	Test
7	scene	seal	Head	Seen	Test
7	heal	seal	Rime	Seen	Test
7	den	seal	Unrelated	Unseen	Test
7	seek	seal	Head	Unseen	Test

APPENDIX B—*Continued*

Sample Set of Test Stimuli Seen by One Participant

Experiment 2

Block	Stimulus	Target	Relation	Seen?	List type
8	tide	rail	Unrelated	Seen	Study
8	jail	rail	Rime	Seen	Study
8	pick	rail	Unrelated	Seen	Study
8	raise	rail	Head	Seen	Study
8	term	rail	Unrelated	Seen	Study
8	race	rail	Head	Seen	Study
8	rave	rail	Head	Seen	Study
8	tote	rail	Unrelated	Seen	Study
8	bail	rail	Rime	Seen	Study
8	nose	rail	Rime	Seen	Study
8	nose	rail	Rime	Seen	Test
8	nail	rail	Rime	Unseen	Test
8	pick	rail	Unrelated	Seen	Test
8	scent	rail	Unrelated	Unseen	Test
8	jail	rail	Rime	Seen	Test
8	rail	rail	Target	Unseen	Test
8	rave	rail	Head	Seen	Test
8	rage	rail	Head	Unseen	Test
8	yolk	rail	Unrelated	Unseen	Test
8	tide	rail	Unrelated	Seen	Test
8	weak	leak	Rime	Seen	Study
9	fun	leak	Unrelated	Seen	Study
9	geek	leak	Rime	Seen	Study
9	leave	leak	Head	Seen	Study
9	leap	leak	Head	Seen	Study
9	fog	leak	Unrelated	Seen	Study
9	cheek	leak	Rime	Seen	Study
9	white	leak	Unrelated	Seen	Study
9	zoom	leak	Unrelated	Seen	Study
9	leash	leak	Head	Seen	Study
9	lean	leak	Head	Unseen	Test
9	soot	leak	Unrelated	Unseen	Test
9	white	leak	Unrelated	Seen	Test
9	leap	leak	Head	Seen	Test
9	weak	leak	Rime	Seen	Test
9	leak	leak	Target	Unseen	Test
9	leave	leak	Head	Seen	Test
9	peak	leak	Rime	Unseen	Test
9	fun	leak	Unrelated	Seen	Test
9	ring	leak	Unrelated	Unseen	Test

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