*Journal of Psycholinguistic Research, Vol. 32, No. 3, May 2003 (© 2003)*

# Silent Letters and Phonological Priming

**Chang H. Lee[1,3] and M. T. Turvey[2]**

*Many written English words contain silent letters. Omitting them produces nonwords pronounced identically to the original words, for example, SALM for PSALM and COLUM for COLUMN. We report two naming and two lexical decision experiments in which targets of 4–11 letters followed primes exposed for 100 ms in mask-prime-mask-target sequences. Priming in SALM-psalm and COLUM-column pairs exceeded priming in orthographic control pairs such as ASTA-pasta and COUSI-cousin, pairs in which pronounced letters are omitted to form the primes. SALM and COLUM, however, were less effective primes than PSALM and COLUMN. Results were discussed in terms of the phonological coherence hypothesis, the role of orthographic codes in filtering phonologically activated representations, and graphemes as reading units.*

**KEY WORDS:** Silent letter; phonological priming; phonological coherence hypothesis; naming; lexical decision.

## INTRODUCTION

Words with silent letters have been used in efforts to uncover phonological involvement in visual word recognition (e.g., Corcoran, 1966; Locke, 1978). These investigations have examined a reader's ability to detect silent letters in the silent reading of text, with a focus on the tendency for a reader to miss unpronounced letters. A number of variables have been found to contribute to this tendency (e.g., whether the letter appears in a stressed or unstressed

---

This research was supported by National Institute of Child Health and Human Development Grant HD-01994 awarded to the Haskins Laboratories, and partly by the starting fund of Pusan National University, Korea. We wish to thank Philip Gough, Georgije Lukatela, and Claudia Carello for their conceptual help.

[1] Pusan National University, Pusan, South Korea, and Haskins Laboratories, New Haven, Connecticut.

[2] University of Connecticut and Haskins Laboratories, New Haven, Connecticut.

[3] To whom all correspondence should be addressed: Department of Psychology, Pusan National University, 30 Changjeon-Dong, Keumjeong-Ku, Pusan, 609–735, South Korea. email: chleehoan@pusan.ac.kr

syllable, Drewnowski & Healy, 1982). Collectively, the effects of these variables permit the inference that readers examine phonological codes in performing a simple visual recognition task that, on the surface, would appear to be indifferent to phonology. In the present line of research, we used words with silent letters to pose a question that complements that which has motivated past usage. We asked about the effect of deleting a silent letter on visual processing. How does the removal of a silent letter from a word affect visual processing relative to the removal of a pronounced letter?

Omitting a word's silent letter produces a nonword that is phonologically identical to the original word. Examples are SALM for PSALM and COLUM for COLUMN. The example of PSALM can be contrasted with a word of the same length and the same initial letter P, where P is pronounced, for example, PASTA. Similarly, the example of COLUMN can be contrasted with a word of the same length and the same final letter N, where N is pronounced, for example, COUSIN. By deleting P in PASTA and N in COUSIN, one produces nonwords ASTA and COUSI that differ phonologically from their source words. More generally, silent-letter stimuli can be compared with stimuli of the same length in which the critical letter is in the same position as the silent letter without necessarily being identical to the silent letter.

In the present article we evaluated the above question about silent letters in terms of priming. We asked whether a nonword derived by deleting a silent letter and a nonword derived by deleting a pronounced letter differed in effectiveness as primes for their source words. For example, does priming in SALM-*psalm* and COLUM-*column* pairs differ in magnitude from priming in ASTA-*pasta* and COUSI-*cousin* pairs? If phonology is activated in visual word processing, then nonword priming of "silent letter" targets should be greater than nonword priming of "pronounced letter" targets, despite equal visual similarity of primes and targets in the two cases.

An investigation of phonological priming with "silent letter" stimuli contrasts with previous investigations. Ideally, the strategy for testing phonological priming should compare a phonologically identical prime and target and a phonologically different prime and target under conditions in which the two pairs are equal in degree of prime-target visual similarity. In French (Ferrand & Grainger, 1992) and English (Lukatela *et al.*, 1998) an approximation to this ideal test of phonological priming has been conducted through pairs such as KLAN-*clan,* SLAN-*clan*. The common degree of orthographic similarity is defined in the preceding example by the same final letter sequence (LAN) in both the prime and target of both pairs. The comparison of SALM-*psalm* and COLUM-*column* pairs with ASTA-*pasta* and COUSI-*cousin* pairs is a different approximation to the ideal strategy. In contrast to the KLAN-*clan* versus SLAN-*clan* approximation, the approximation to the ideal strategy afforded by "silent letter" stimuli eliminates any possible difference in orthographic similarity that might arise because of the necessity of using different critical letters. In the preceding example, a given visual feature metric might find that K and S differ in the number of visual features they share in common with c (Lukatela *et al.*, 2001).

In sum, "silent letter" stimuli provide an alternative approximation to the ideal strategy for investigating phonological priming. Taking advantage of these stimuli and the gain in prime-target orthographic similarity they afford—consider SALM-*psalm* versus ASTA-*pasta*—requires controls for the difference in targets. Equating the targets in frequency and length eliminates major potential differences of relevance to word recognition speed. Other potential differences can be eliminated by relating SALM-*psalm* and ASTA-*pasta* to prime-target pairs with the same targets. In the present experiments, the control prime-target pairs were of the form asterisks-*psalm*, asterisks-*pasta* and PSALM-*psalm*, PASTA-*pasta*.

We evaluated the effectiveness of primes of the SALM type in both the rapid naming and lexical decision tasks. Current accounts of visual word recognition differ in their expectations for phonological priming of target naming and target lexical decision at very brief prime-target intervals. The different expectations are grounded in different assumptions about the leading code. If the leading code is visual, as in the dual-route cascade (DRC) model (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), then phonological priming at very brief time scales should be limited in naming (perhaps to cases in which primes are nonwords or rare regular words) and absent in lexical decision (see below). If the leading code is presumed to be phonological, as is the case, for example, in some adaptive resonance models (e.g., Van Orden & Goldinger, 1994), then phonological priming at very brief time scales is expected for both naming and lexical decision.

In the four experiments of the present article, two with naming and two with lexical decision, the prime-target pairs were embedded in a four-field sequence of mask-prime-mask-target (e.g., Lukatela & Turvey, 1994, 1996; Lukatela, Frost, & Turvey, 1999). The post-prime, pretarget mask seems to be more important to the demonstration of pseudohomophone priming (TODE-*toad* superior to TODS-*toad*) at shorter prime-target onset asynchronies (e.g., 60 ms) than at longer prime-target onset asynchronies (e.g., 250 ms) (Lukatela & Turvey, 1994). One reading of the latter observation is that orthographic priming is limited to very short onset asynchronies, arising from briefly persisting activity in the input layer of visual features (Ferrand & Grainger, 1994). Consequently, with the insertion of a patterned mask between the nonword prime and the word target, the persistent visual activity that might ordinarily obscure phonological priming at brief onset asynchronies is markedly reduced or eliminated (Lukatela & Turvey, 1994).

With suitably chosen duration parameters, the four-field presentation sequence minimizes explicit prime identification and the use of conscious strategies. Choice of parameters in the present research was constrained by the facts that primes ranged in length from 3 to 10 letters, with the critical letter manipulation occurring in the initial, intermediate, and final positions. Selected durations of prime and post-prime mask had to accommodate the potentially wide variation in effective processing time because of length and critical letter position and, simultaneously, satisfy the requirement of minimizing strategic processing. In our experiments we attempted to meet these criteria with prime and post-prime mask exposures of approximately 100 ms each.

## EXPERIMENTS 1 AND 2: PRIMING WITH AND WITHOUT SILENT LETTERS IN THE RAPID NAMING TASK

Experiments 1 and 2 differed only in respect to the baseline for evaluating priming in SALM-*psalm* and COLUM-*column* prime-target pairs relative to ASTA-*pasta* and COUSI-*cousin* prime-target pairs. In Experiment 1, the baseline was provided by naming performance on the corresponding pairs formed by replacing the nonword primes by a row of asterisks. In Experiment 2, the baseline was provided by naming performance on the corresponding pairs formed by replacing the nonword primes by the identity primes (e.g., SALM and ASTA replaced by PSALM and PASTA, respectively).

### Method

#### *Participants*

There were 36 participants in Experiment 1 and 32 different participants in Experiment 2. The participants were students enrolled at the University of Connecticut. They participated in the experiment to satisfy a course requirement. Each participant in each experiment was assigned to one of two groups by order of appearance at the laboratory.

#### *Materials*

The nonword-word prime-target pairs are shown in the Appendix. There were 29 pairs of the kind SALM-psalm, COLUM-column and 29 pairs of the kind ASTA-pasta and COUSI-cousin. Frequency was matched across the two kinds of nonword-word pairs using the CELEX database (Baayen, Piepenbrock, & van Rijn, 1993). The average frequency of the "silent letter" targets was 535.02 ± 1157.80, and the average frequency of the "pronounced letter" targets was 575.86 ± 1305.71. The two kinds of targets were also matched in length (see Appendix). In Experiment 1, 58 baseline pairs were produced by replacing the nonword in each nonword-word pair by a row of asterisks, where the number of asterisks was equal to the number of letters in the target word. In Experiment 2, 58 baseline pairs were produced by replacing the nonword in each nonword-word pair by the word in the pair.

The background or "filler" pairs in the experiments were 72 in number and were constructed with word primes, for example, COP-copy. Use of word primes was for the purpose of countering the potential bias toward phonological processing induced by the nonword primes.

### *Design*

Two counterbalanced lists (A and B) were created, each consisting of 58 pairs of stimuli. In each list, 29 target words were paired with a nonword prime and 29 target words were paired either with a row of asterisks or with themselves (identity primes). In Experiment 2, for example, the two lists related as follows: if List A included SALM-*psalm*, PASTA-*pasta*, COLUMN-*column*, and COUSI-*cousin*, then List B included PSALM-*psalm*, ASTA-*pasta*, COLUM-*column*, and COUSIN-*cousin*. Half of the participants (Group A) saw List A, and the other half of the participants (Group B) saw List B. Participants in both Groups A and B saw all 72 filler pairs.

In this design Group is a factor in the analysis of variance (ANOVA) but an effect of Group and interactions involving Group are ignored. Group A experiences the control stimuli (e.g., PASTA-*pasta*, COLUMN-*column*) that correspond to Group B's experimental stimuli (ASTA-*pasta*, COLUM-*column*) and, conversely, Group B experiences the control stimuli (PSALM-*psalm*, COUSIN-*cousin*) that correspond to Group A's experimental stimuli (SALM-*psalm*, COUSI-*cousin*). The relation between target type (with a silent critical letter, such as *psalm*, or with a pronounced critical letter, such as *pasta*) and prime type (nonword versus asterisks or word) within a group is therefore not meaningful.

### *Procedure*

Participants, run one at a time, sat in front of the monitor of a DLL computer. The viewing distance was about 60 cm in a normally illuminated room. The refresh rate of the Pentium monitor was 78 Hz, making a refresh cycle (i.e., a "tick") equal to 12.9 ms. All stimuli were centered at the same central point on the screen such that a five-letter target superimposed on its four-letter prime, for example, would not have letters occupying the exact same locations as the letters of the prime. All stimuli were presented as white characters on a dark background. Each trial consisted of a sequence of four visual events: (1) a row of five hash marks for 490.2 ms; (2) a row of asterisks (Experiment 1) or an uppercase identity prime (Experiment 2) or an uppercase nonword prime (Experiments 1 and 2) for 103.2 ms; (3) a row of ampersands for 116.1 ms; and (4) a lowercase word target for 1400 ms. All interstimulus intervals were 0 ms. Masks and linguistic stimuli were spatially overlapping, with the pre- and post-prime masks containing the same number of symbols as the prime's target. The durations of visual displays (2) and (3) were chosen to reduce the opportunity for strategic (conscious) processing (e.g., Lesch & Pollatsek, 1993) and to permit the processing of long letter strings (63% of the nonword primes consisted of five letters or more). Controlled presentation of the sequence of stimuli at the identified temporal parameters was by means of DMASTR software (developed at Monash University and University of Arizona by K. I. Forster and J. C. Forster).

Participants were instructed that a sequence of stimuli would appear at the center of the computer screen in rapid succession and that the task was to name the lowercase (last) stimulus as quickly and as accurately as possible. They were also instructed not to correct any pronunciation errors once committed. The experimenter recorded pronunciation errors and other errors (e.g., hesitations).

## Results and Discussion

All latencies above and below 2 standard deviations of the means of each participant were excluded. Also excluded were target responses recorded as pronunciation errors. In both experiments the average for each of the four conditions was computed for each participant. Mean latencies and error rates across participants for Experiments 1 and 2 are presented in Tables I and II respectively.

### *Experiment 1*

A Group × Target (silent critical letter versus pronounced critical letter) × Prime (nonword versus asterisks) ANOVA was conducted with subjects as the error term. (See discussion of relative values of subject and items analyses by Raaijmakers, Schrijnemakers, & Gremmen, 1999, for the situation in which stimulus selection is highly constrained as in the present research). The important interaction of target and prime was significant [$F(1, 35) = 14.76$, $SEM = 8236.56$, $p < .001$]. Whereas SALM-*psalm* was faster than asterisks-*psalm* by 49 ms, [$F(1,35) = 67.28$, $SEM = 50467.82$, $p < .0001$], ASTA-*pasta* was faster than asterisks-*pasta* by only 19 ms [$F(1,35) = 7.6$, $SEM = 28780.01$, $p < .01$]. The Target × Prime interaction was absent in the ANOVA on errors ($p > .05$).

**Table I.** Mean Naming Latencies (in ms) and Percentage of Errors as a Function of Prime Type and Target Type in Experiment 1

| | Target | |
|---|---|---|
| Prime type | Silent ("psalm") | Nonsilent ("pasta") |
| Nonword | | |
| M | 561 | 592 |
| SE | 14 | 15.5 |
| % Error | 4.4 | 4.3 |
| Asterisks | | |
| M | 610 | 611 |
| SE | 14.2 | 14.4 |
| % Error | 2.8 | 3.1 |
| Difference | −49 | −19 |

Two further ANOVAs on the latency measure were conducted, one with the additional factor of Word Length (12 stimuli of 4–6 letters versus 17 stimuli of 7–11 letters, see Appendix) and one with the additional factor of Critical Position. The latter factor refers to where the deleted letter was located in the letter string. More specifically, it was a comparison of first position (15 stimuli) versus an intermediate or final position (14 stimuli). The two factors were not fully distinct given that shorter targets, more so than longer targets, tended to pair with primes with initial letters deleted.

**Table II.** Mean Naming Latencies (in ms) and Percentage of Errors as a Function of Prime Type and Target Type in Experiment 2

| | Target | |
|---|---|---|
| Prime type | Silent ("psalm") | Nonsilent ("pasta") |
| Nonword | | |
| M | 521 | 538 |
| SE | 14.3 | 13.6 |
| % Error | 3.1 | 3.6 |
| Identity | | |
| M | 500 | 499 |
| SE | 14.3 | 14.2 |
| % Error | 2.1 | 1.9 |
| Difference | 21 | 39 |

Behind both ANOVAs was the question of whether the position of the critical letter mattered. For both ANOVAs, the additional factor did not affect the Prime × Target interaction ($F < 1$ in both cases).

### *Experiment 2*

The Group × Target (silent critical letter versus pronounced critical letter) × Prime (nonword versus identity) ANOVA on latencies found a significant Prime × Target interaction [$F(1,31) = 4.9$, $SEM = 2685.16$, $p < .05$]. Whereas SALM-*psalm* was slower than PSALM-*psalm* by only 21 ms, [$F(1, 31) = 9.09$, $SEM = 6798.19$, $p < .01$], ASTA-*pasta* was slower than PASTA-*pasta* by 39 ms [$F(1,31) = 58.46$, $SEM = 23042.08$, $p < .0001$]. There was an overall advantage for identity primes over nonword primes [$F(1,31) = 46.45$, $SEM = 28366.01$, $p < .0001$]. No effects were significant in the error analysis (all $ps > .05$).

As in the analysis of Experiment 1, two additional ANOVAs were conducted on the latency measure. Neither Target × Prime × Word Length nor Target × Prime × Critical Position were significant [$F(1,62) = 1.2$, $SEM = 439.21$, $p > .05$, and $F < 1$, respectively].

It is important to note that the experimental results confirmed the equivalency of the set of silent letter stimuli and the set of nonsilent letter stimuli in respect to basic parameters. As is evident from inspection of Tables I and II, pronunciation latencies in the baseline conditions (asterisks and identity) were the same for both stimulus sets. This confirmation of the equivalency of the silent and nonsilent stimuli gives added confidence that the observed priming difference between SALM and ASTA was real.

Experiments 1 and 2 corroborate previous research, with the naming task showing an advantage for nonword primes homophonic with their targets relative to orthographic controls (e.g., Lukatela & Turvey, 1994, 2000). In their Experiment 4, Lukatela and Turvey (2000) found that nonword primes differing from their targets by a single initial letter (e.g., KLIP-*clip*) or a single intermediate letter (e.g., HEET-*heat*) facilitated the naming of their targets relative to orthographic control primes (e.g., PLIP-*clip*, HERT-*heat*). Further, they found that the degree of priming was the same for both initial different (KLIP-*clip*) and intermediate different (HEET-*heat*) primes. The finding in the present Experiments 1 and 2 that position of the critical letter was not decisive in determining the degree of priming is consistent with this latter observation of Lukatela and Turvey (2000). It is also counter to an interpretation of the present data in terms of the onset effect (Forster & Davis, 1991; Kinoshita, 2000). A degree of circumspection is required, however, in drawing these conclusions. The division into sets of critical initial letter and critical intermediate letter was somewhat confounded with word length. Relatively few of the targets with the critical letter in intermediate position were short words (six or fewer letters).

Results from previous investigations of fast time-scale priming within the four-field procedure have been equivocal on the issue of whether priming by a nonword homophonic with the target word was equal to the target word itself. Identity priming in the naming task was often numerically superior but never statistically superior to pseudohomophone priming in the experiments of Lukatela and Turvey (1994). Their stimuli were monosyllabic. In the present Experiments 1 and 2, with monosyllabic and multisyllabic stimuli, an advantage for identity priming over pseudohomophone priming was clearly evident. This clear priming advantage of PSALM over SALM, despite their identical phonology, indicates that factors other than phonology contributed to priming in the present experiments. (Some of the possible factors are detailed in the General Discussion.)

## EXPERIMENTS 3 AND 4: PRIMING WITH AND WITHOUT SILENT LETTERS IN THE LEXICAL DECISION TASK

The demonstration of an advantage of silent-letter primes in the naming task is open to explanation in terms of articulatory programs. The naming process is generally assumed to involve decoding letters, assembling a phonological code, and producing articulatory motor output (e.g., McCrae, Jared, & Seidenberg, 1990). Because the target had to be spoken in Experiments 1 and 2, the prior but implicit assembly of an articulatory program that matched that of the target in SALM-*psalm* pairs would have been beneficial. In contrast, if targets have to be processed for their lexical status ("Is this a word?") rather than named, then no articulatory program needs to be assembled and no benefits should accrue from prior program assembly in SALM-*psalm* pairs relative to ASTA-*pasta* pairs. On the other hand, if the assembling of a *phonological code* is mandatory, regardless of the output (naming or lexical decision), then prior phonology assembly in SALM-*psalm* pairs relative to ASTA-*pasta* pairs should be beneficial to lexical decision.

It is instructive to consider how the DRC model addresses the contrast between SALM-*psalm* and ASTA-*pasta* in the lexical decision task. In the model's architecture, processes cascade on the *lexical route* from the initial level of visual features as follows: letter detection, orthographic whole-word lexical representations, phonological whole-word lexical representations, phoneme units. The cascade of processes on the *nonlexical route* begins from the same starting point but orders differently as: serial grapheme-phoneme conversion by rule, phoneme units, phonological whole-word lexical representations, orthographic whole-word lexical representations, letter detection.

We conducted simulations of priming in the lexical decision task under the standard operating characteristics of the DRC model.[4] Stimuli were limited to monosyllables to conform to the current capabilities of the model. Several interstimulus intervals between prime and target were examined, with 20 processing cycles defining the shortest interval (see Rastle & Coltheart, 1999). There were two noteworthy findings of the simulations. First, whether a word was a prime or a target, criterion-level activity was realized within the orthographic lexicon before the letter-to-phoneme conversion on the nonlexical route.[5] Second, the beneficial transfer of prime processing to target processing was realized strictly through the lexical route. That is to say, for the simulations, the number of shared letters was the significant factor, not the number of phonemes and phonotactic constrains common to prime and target. The implication of the simulations is that the similarity in priming between, for example, HAF-*half* and HALF-*half* should not differ in the lexical decision task from the similarity in priming between HEP-*help* and HELP-*help*. Generalizing, we might expect that processing models like the DRC model are unlikely to predict a priming advantage for nonword primes produced by deleting a silent letter (e.g., SALM) relative to nonword primes produced by deleting a corresponding pronounced letter (e.g., ASTA).

The two lexical decision experiments, Experiments 3 and 4, paralleled the two naming experiments. That is, Experiments 3 and 4 differed only in respect to the baseline for evaluating priming in SALM-*psalm* and COLUM-*column* prime-target pairs relative to ASTA-*pasta* and COUSI-*cousin* prime-target pairs. In Experiment 3, the baseline was provided by lexical decision performance on the corresponding pairs formed by replacing the nonword primes by a row of asterisks. In Experiment 4, the baseline was provided by lexical decision performance on the corresponding pairs formed by replacing the nonword primes by the identity primes (e.g., SALM and ASTA replaced by PSALM and PASTA, respectively).

## Method

### *Participants*

There were 32 participants in each experiment. None had participated in Experiments 1 and 2, and none participated in both Experiments 3 and 4.

---

[4] The DRC model and standard parameters can be found at the Web address www.maccs.mq.edu.au/~max/DRC.

[5] In large part, the preceding outcome is the consequence of two standard features of the DRC model: (i) the 10-cycles delay of the onset of activity on the nonlexical route relative to the onset of activity on the lexical route and (ii) the 17 cycles needed for the left-to-right computing of phonemes.

The participants were students enrolled at the University of Connecticut. They participated with consent in the experiment to satisfy a course requirement. Each participant in each experiment was assigned to one of two groups by order of appearance at the laboratory.

### *Materials*

Apart from the addition of 58 filler prime-target pairs with nonword targets, the stimuli of Experiment 3 were identical to those of Experiment 1 and the stimuli of Experiment 4 were identical to those of Experiment 2. The nonword targets in the filler pairs were orthographically legal and pronounceable.

### *Design and Procedure*

These followed the Design and Procedure of Experiments 1 and 2 with the naming task replaced by the lexical decision task.

## Results and Discussion

All latencies above and below 2 standard deviations of the mean of each participant were excluded. Also excluded were target responses recorded as decision errors. In both experiments the average for each of the four conditions was computed for each participant. Mean latencies and error rates across participants for Experiments 3 and 4 are presented in Tables III and IV, respectively.

**Table III.** Mean Lexical Decision Latencies (in ms) and Percentage of Errors as a Function of Prime Type and Target Type in Experiment 3

| | Target | |
|---|---|---|
| Prime type | Silent ("psalm") | Nonsilent ("pasta") |
| Nonword | | |
| M | 565 | 594 |
| SE | 15.2 | 15 |
| % Error | 4.7 | 5.2 |
| Asterisks | | |
| M | 636 | 634 |
| SE | 16.3 | 15.1 |
| % Error | 4.1 | 5.5 |
| Difference | −71 | −40 |

### *Experiment 3*

A Group × Target (silent critical letter versus pronounced critical letter) × Prime (nonword versus asterisks) ANOVA revealed a significant Target × Prime interaction [$F(1,31) = 5.77$, $SEM = 8240.61$, $p < .05$]. Whereas SALM-*psalm* was faster than asterisks-*psalm* by 71 ms, [$F(1,31) = 14.57$, $SEM = 87478.77$, $p < .001$]. ASTA-*pasta* was faster than asterisks-*pasta* by only 40 ms [$F(1,31) = 2.71$, $SEM = 25509.40$, $p > .05$]. The Target × Prime interaction was absent in the ANOVA on errors ($p > .05$). Additional ANOVAs on the latency data found that neither Target × Prime × Word Length nor Target × Prime × Critical Position were significant (both $Fs < 1$).

### *Experiment 4*

The Group × Target (silent critical letter versus pronounced critical letter) × Prime (nonword versus identity) ANOVA on latencies found a significant Prime × Target interaction [$F(1,31) = 19.53$, $SEM = 4559.73$, $p < .0001$]. Whereas SALM-*psalm* was slower than PSALM-*psalm* by only 18 ms [$F(1,31) = 7.62$, $SEM = 5057.82$, $p < .01$]. ASTA-*pasta* was slower than PASTA-*pasta* by 42 ms [$F(1,31) = 36.04$, $SEM = 27760.32$, $p < .0001$]. There was an overall advantage for identity primes over nonword primes [$F(1,31) = 23.55$, $SEM = 28258.42$, $p < .0001$]. No effects were significant in the error analysis (all $ps > .05$). Additional ANOVAs on the latency data found that neither Target × Prime × Word Length nor Target × Prime × Critical Position were significant ($Fs < 1$ in both cases).

Again, it is important to note that both experiments confirmed the equivalency of the set of silent letter stimuli and the set of nonsilent letter

**Table IV.** Mean Lexical Decision Latencies (in ms) and Percentage of Errors as a Function of Prime Type and Target Type in Experiment 4

| | Target | |
|---|---|---|
| Prime type | Silent ("psalm") | Nonsilent ("pasta") |
| Nonword | | |
| M | 556 | 577 |
| SE | 15.3 | 16 |
| % Error | 4.1 | 3.9 |
| Identity | | |
| M | 538 | 535 |
| SE | 15.9 | 14.9 |
| % Error | 3.7 | 3.2 |
| Difference | 18 | 42 |

stimuli in respect to basic parameters. Inspection of Tables III and IV reveals that the lexical decision latencies in the baseline conditions (asterisks and identity) were approximately the same for both sets. As with Experiments 1 and 2, this confirmation of the equivalency of the two sets in the lexical decision experiments gives added confidence that the observed priming difference between SALM and ASTA was real.

The results of Experiments 3 and 4 are consistent with previous lexical decision experiments showing that nonword primes homophonic with their targets facilitate target processing relative to orthographic controls (e.g., Ferrand & Grainger, 1992, 1994; Lukatela *et al.*, 1998). SALM and ASTA share the same number of letters in common with their targets, but they do not share the same number of phonemes, and that difference makes a difference in primed lexical decision.

In conjunction, the results of the present lexical decision and naming experiments suggest that the two tasks are more similar than they are different. One presumed difference between naming and lexical decision is that naming is based primarily on activation of phoneme units and lexical decision is based primarily on activation of word units (e.g., Coltheart *et al.*, 2001; Lukatela, Carello, & Turvey, 1990; Van Orden & Goldinger, 1994). Another presumed difference is that naming time is the purer measure of visual word recognition given that naming involves many fewer post-access decision processes than does lexical decision (e.g., Forster, 1990). What the present data suggest is that, despite surface differences, naming and lexical decision are alike in a fundamental way: the performance of each task is mediated by phonological codes.

## GENERAL DISCUSSION

In the present research we have investigated the effect on visual word processing of deleting a silent letter. Essentially, we have asked whether the nonword produced by deleting a silent letter is more like its source word than the nonword produced by deleting a pronounced letter is like its source word. Deleting a silent letter preserves the source word's phonology but not its orthography; deleting a pronounced letter preserves neither the source word's phonology nor its orthography. Using a priming-with-masking procedure that severely curtailed the time available for processing the prime, we found that "silent letter" nonword primes facilitated identification of their source words better than "pronounced letter" nonword primes. Specifically, we found that "silent letter" nonword primes (i) produced 30 and 31 ms more facilitation in the naming and lexical decision tasks, respectively, than "pronounced letter" nonword primes, and (ii) produced only 21 and 18 ms less facilitation than identity primes in the naming and lexical decision tasks, respectively, compared to 40 and 42 ms less facilitation by "pronounced letter" nonword primes. In sum, it seems that the nonword produced by deleting a silent letter is more like its source word than the nonword produced by deleting a pronounced letter is like its source word. The greater likeness of "silent letter" primes to their source words lies in their shared phonology.

The outcome of the present research is consonant with a large number of studies showing that phonological codes are assembled early and routinely in visual word processing (e.g., Brysbaert, Van Dyek, & Van de Poel, 1999; Ferrand & Grainger, 1992, 1994; Frost, 1998; Lesch & Pollatsek, 1998; Lukatela & Turvey, 1998; Lukatela *et al.*, 1998, 1999; Luo, 1996; Perfetti, Zhang, & Berent, 1992; Rayner, Sereno, Lesch, & Pollatsek, 1995; Rouibah, Tiberghien, & Lupker, 1999; Van Orden & Goldinger, 1994; Xu & Perfetti, 1999; Ziegler & Jacobs, 1995). Arguably, the clearest evidence for the rapid assembly of phonology in the processing of letter strings is provided by priming experiments of the present kind using briefly presented pattern-masked primes (Grainger & Ferrand, 1996). Typically, in such experiments the phonological and orthographic similarity of prime and target are the principal manipulations. The deduction that phonology is assembled or activated quickly is based on the demonstration that there is an effect of phonological similarity over and above an effect of orthographic similarity. The common finding of Experiments 1–4, using briefly presented pattern-masked primes, was that priming in SALM-*psalm* and COLUM-*column* pairs was superior to priming in pairs that were equally similar visually, namely, ASTA-*pasta* and COUSI-*cousin* pairs. In sum, approximating the ideal strategy for evaluating phonological priming through manipulations of "silent letter" stimuli corroborated the results obtained with the more standard approximations to the ideal strategy (see introduction).

The evidence presented here and elsewhere for a fast-acting computation of phonology in both the naming and lexical decision tasks is consistent with the view that a word's phonology plays the leading role rather than a subsidiary role in visual word recognition. This view is expressed most usefully through the *phonological coherence hypothesis* (Van Orden & Goldinger, 1994; Van Orden, Pennington, & Stone, 1990). Van Orden *et al.* base this hypothesis on the claims that the mapping is most systematic, most nearly 1:1, between orthographic structure and phonological structure, least systematic between orthographic structure and semantic structure, and intermediate in systematic form between phonological structure and semantic structure (but see Seidenberg, 1995). The consequence of a 1:1 mapping in dynamic terms is that resonance or self-consistency is achieved rapidly within the matrix of connections linking the processing units of the two structures. As expressed in adaptive resonance theory (Grossberg, 1982; Grossberg & Stone, 1986), a resonant mode is achieved when the activity excited in a given layer of processing units from below matches that excited from above. In the latter framework, the phonological coherence hypothesis is the claim that phonological forms are coded at the outset closest to their respective attractors and therefore are the earliest codes to achieve resonance or coherence (Gottlob, Goldinger, Stone, & Van Orden, 1999; Van Orden & Goldinger, 1994; Van Orden *et al.*, 1990). Phonological codes can thus act to stabilize other concurrent and ongoing linguistic processes.

In its most basic form, the phonological coherence hypothesis is the hypothesis that the time to achieve a unique phonological code sets the lower limit on latency of visual word recognition. In this most basic form, the hypothesis has led to the correct prediction that there are phonological conditions under which nonwords can activate semantics faster than words (Lukatela *et al.*, 1998). It has also led to the correct prediction that a phonologically inconsistent word will fail to prime itself at short time scales sufficient for a phonologically consistent word to prime itself (Lukatela *et al.*, 1999).

An important question raised by the present research is that of why identical spelling of prime and target produces processing benefits beyond those of identical phonology. Both Experiment 2 with naming as the response and Experiment 4 with lexical decision as the response found a reliable advantage for identity primes over the pseudohomophone primes produced by deleting the silent letter in the identity primes. Previous experiments with rapid naming have found priming by a homophonic nonword to be typically smaller than identity priming in magnitude but not to a degree sufficient to pass statistical tests of significance (e.g., Lukatela and Turvey, 1994). In naming experiments that varied the number of letters distinguishing a pseudohomophone from its target, greater proximity to identity tended to produce greater priming numerically but not always statistically (Lukatela & Turvey, 2000; see their Figures 1 and 2). The sizes of the phonological priming effects in the cited naming experiments were not large, raising the question of whether the observed instances of statistical nonsignificance reflected power issues rather than processing characteristics.

Dual route theories (e.g., Coltheart *et al.*, 2001) would predict a larger priming effect for PSALM-*psalm* and COLUMN-*column* than SALM-*psalm* and COLUM-*column*, respectively. In the dual-route cascaded (DRC) model, processes cascade on the *lexical route* from the initial level of visual features as follows: letter detection, orthographic whole-word lexical representations, phonological whole-word lexical representations, phoneme units. The cascade of processes on the *nonlexical route* from the same starting point orders as: serial grapheme-phoneme conversion by rule, phoneme units, phonological whole-word lexical representations, orthographic whole-word lexical representations, letter detection.

In the DRC model, the phonemic code needed to constrain naming would be produced over both the faster-acting lexical route and the slower-acting nonlexical route. The faster route produces a phonemic code via successive activation of whole-word orthographic and phonological representations; the slower route generates a phoneme code by grapheme-phoneme correspondence rules. On the slower, nonlexical route, PSALM and SALM, for example, would activate the same phoneme code to the same degree. In contrast, on the faster lexical route, PSALM would activate the relevant phoneme code to a greater degree than SALM. Whereas PSALM would strongly activate its whole-word representations in the orthographic and phonological lexicons, SALM would activate the orthographic and phonological lexical representations of PSALM comparatively weakly because of the omitted letter. It follows, therefore, that whether the lexical route dominates or whether the two routes combine in producing PSALM's phoneme code, it will be the case that the phoneme code constraining that needed for naming in Experiment 2 will be activated more quickly and more strongly by PSALM than by SALM.

Very much the same argument would address the advantage of the identity prime in the lexical decision task of Experiment 4. As noted, over the lexical route, PSALM would activate strongly its whole-word orthographic representation and thereby facilitate the decision on the subsequent *psalm*. In contrast, over the lexical route, SALM would prepare the target's orthographic unit, weakly resulting in a smaller facilitation of the decision on the target. The identity prime's advantage at the level of the orthographic lexicon would not be compromised by processing over the nonlexical route. Over the latter route, PSALM and SALM would activate the target's orthographic representation in equal degree.

The expected advantage for identity priming derived from the architecture of the dual route cascaded model is offset, however, by ambiguity in predicting an advantage at brief prime-to-target intervals for SALM over ASTA. On the lexical route, both SALM and ASTA would activate the orthographic and phonological whole-word units corresponding to their targets only weakly. In contrast, SALM would have an advantage on the nonlexical route. It would activate the phonological representation of *psalm* and thereby activate the orthographic representation of *psalm* to substantial degrees. ASTA, in comparison, would produce, on the nonlexical route, little activation of the lexical representations of *pasta*. However, whether the benefits for SALM-*psalm* pairs resulting from nonlexical processing can take effect depends on the relative time scales of nonlexical and lexical processing. In the DRC model with standard parameters (Rastle & Coltheart, 1999), the nonlexical cascade of processes lags the lexical cascade sufficiently to make contributions of the nonlexical route unlikely when the prime precedes the target by a small amount of time as in the present and similar experiments. A modification of parameters that yields comparable processing speeds on the two routes would eliminate uncertainty about the DRC model's ability to accommodate the present results.

Within the DRC model, advantages for pseudohomophones such as SALM and COLUM are anchored in the whole-word representations stored in the phonological lexicon. In a parallel distributed processing system such as that proposed by Seidenberg and McClelland (1989) and Plaut, McClelland, Seidenberg, and Patterson (1996), stored whole-word representations do not exist. Consequently, a pseudohomophone advantage cannot be due to homophony between a nonword and the lexical representation of a word. That is, it cannot be the case that SALM is a better prime than ASTA simply because, in storage, there is a word that sounds exactly like SALM but there is no word that sounds exactly like ASTA. In explaining why a pseudohomophone is typically named faster than an ordinary nonword (in the nonprimed naming task), Seidenberg, Petersen, MacDonald, and Plaut (1996) focused on how the computations (i) from orthography to phonology and (ii) from phonology to articulatory output are affected by the degree to which nonwords are "wordish." With this focus, they asked whether pseudohomophones and ordinary nonwords that are closely matched in terms of orthographic and phonological properties would differ in speed of naming. The finding that pseudohomophones were named faster under such conditions, and that the advantage persisted when naming was delayed, led them to conclude that the site of the pseudohomophone advantage was (ii) (see also Herdman, LeFevre, & Greehham, 1996).

For the present priming task with naming as the response, a distributed processing model (e.g., Seidenberg & McClelland, 1989) would predict greater priming in SALM-*psalm* and COLUM-*column* pairs than ASTA-*pasta* and COUSI-*cousin* pairs. It would do so on the assumption that the phonology relevant to constraining the naming of the target is generated fully in the case of SALM and only partially in the case of ASTA. The priming superiority of PSALM over SALM suggests, however, that despite the sameness of the computed phonological output, that computed in the case of PSALM is of better quality and/or greater strength than that computed in the case of SALM. One interpretation of the source of this difference in quality and/or strength is that in the orthography-to-phonology mapping, the weighted connection between PS and /s/ reinforces the weighted connection between S and /s/ (compare with activation of /f/ by F, PH, and GH in Schneider, Healy & Gesi, 1991). The latter fact enhances the speed and degree of activation of /salm/ in response to PSALM relative to the speed and degree of activation of /salm/ in response to SALM.

The distributed processing explanation for the primed naming data of Experiments 1 and 2 applies in similar form to the primed lexical decision data of Experiments 3 and 4. In distributed processing models, lexical decision to unprimed letter strings is interpreted largely in terms of *familiarity*. Lexical processing within such models (specifically Plaut *et al.*, 1996; Seidenberg & McClelland, 1989) does not involve accessing stored word codes (there aren't any) but involves, rather, the activation of different types of information. Under some conditions it is assumed that familiarity judgements within the lexical decision task can be based successfully on the computed orthographic pattern (compare with Balota & Chumbley, 1984). Under other conditions (e.g., high visual similarity of words and nonwords), the familiarity judgements are based on the computed phonological pattern. When conditions are such that neither the orthographic or phonological outputs suffice, then computed semantic patterns are assessed for familiarity. Most generally, all three kinds of information are likely to be exploited.

In the similar vein, the phonological coherence hypothesis brings to the fore a new question: if phonological codes lead in the manner suggested, then what is the role of the slower and less stable orthographic to semantic mapping? One possible answer is that it functions as a "spelling check." If activation of semantics is led by phonological codes, then the role of orthographic codes can be conceived as that of filtering appropriately and inappropriately activated representations (e.g., Lesch & Pollatsek, 1993; Luo, 1996; Seidenberg *et al.*, 1996; Van Orden, Johnston, & Hale, 1988). This spelling check idea addresses the advantage of identity priming over homophonic priming evident in Experiments 2 and 4. Although the semantic features of "psalm" are activated phonologically by both PSALM and SALM, only the activation by PSALM is appropriate. A priming advantage of PSALM over SALM could arise as follows. In the case of PSALM, the spelling check amplifies the activation of the semantic features of "psalm" and the feedback to the corresponding phonological code. In contrast, in the case of SALM, the spelling check reduces both the activation and feedback.

A final comment can be directed at the more general issue of the status of silent letters: are they processed and represented differently from pronounced letters (Ehri, 1980)? The results of the present experiments provide little support for the hypothesis that silent letters are special in word perception by fluent adult readers. The facts that (i) identity priming was identical for words with and without silent letters and (ii) identity priming of words with silent letters was superior to priming by nonwords formed by deleting the target's silent letter, clearly indicate that silent letters function equivalently to pronounced letters in the earliest stages of visual word recognition. These same facts, when interpreted in the context of current models, are consistent with the understanding that phonemes (e.g., /s/) become connected to both the single letters (S) and the groupings of letters (PS) that are frequently used to represent them (e.g., Rey, Ziegler, & Jacobs, 2000; Schneider, Healy, & Gesi, 1991). That is to say, they are consistent with the idea that the earliest levels of visual word processing are constrained by graphemes—letter patterns at several grain sizes that map to the phonemes of the language (Rey *et al.*, 2000).

## APPENDIX A

Targets in Experiments 1–4. (Double underscores indicate the silent letter and the corresponding nonsilent letter.)

| Silent | Nonsilent | Silent | Nonsilent |
|---|---|---|---|
| gnaw | gala | condemn | nucleus |
| half | help | diamond | pasture |
| czar | noun | scholar | surgeon |
| numb | mini | kitchen | council |
| knee | taxi | scissors | scramble |
| knoll | kiosk | scenario | sanction |
| psalm | pasta | pneumonia | pantomime |
| knife | kitty | wholesome | worthless |
| knead | comma | Christmas | challenge |
| knock | logic | raspberry | turquoise |
| column | cousin | champagne | passenger |
| meadow | monkey | breakfast | professor |
| psychic | premium | rheumatism | antibiotic |
| writing | western | cholesterol | predominate |
| wrestle | distort | | |

## REFERENCES

Baayen, R. H., Piepenbrock, R., & van Rijn, H. (1993). *The CELEX lexical database* [CD-ROM]. Philadelphia, PA: University of Pennsylvania, Linguistic Data Consortium.

Balota, D. A., & Chumbley, J. I. (1984). Are lexical decisions a good measure of lexical access? The role of word frequency in the neglected decision stage. *Journal of Experimental Psychology, Human Perception and Performance, 10,* 340–357.

Brysbaert, M., Van Dyck, G., & Van de Poel, M. (1999). Visual word recognition in bilinguals: Evidence from masked phonological priming. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 137–148.

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review, 108,* 204–256.

Corcoran, D. W. J. (1996). An acoustic factor in letter cancellation. *Nature, 210,* 658.

Drewnowski, A., & Healy, A. F. (1982). Phonetic factors in letter detection: A reevaluation. *Memory and Cognition, 10,* 145–154.

Ehri, L. (1980). The role of orthographic images in learning printed words. In J. Kavanagh. & R. L. Venezky (Eds.), *Orthography, reading and dyslexia* (pp. 155–170). Baltimore, MD: University Park Press.

Ferrand, L., & Grainger, J. (1992). Phonology and orthography in visual word recognition: Evidence from masked now-word priming. *The Quarterly Journal of Psychology A, 45,* 353–372.

Ferrand, L., & Grainger, J. (1994). Effects of orthography are independent of phonology in masked form priming. *The Quarterly Journal of Experimental Psychology A, 47,* 365–382.

Forster, K. (1990). Lexical processing. In D. Osherson, & H. Lasnik (Eds.), *An invitation to cognitive science: Language* (pp. 95–132). Cambridge, MA: MIT Press.

Forster, K., & Davis, C. (1991). The density constraint on form-priming in the naming task: Interference effects from a masked prime. *Journal of Memory and Language, 30,* 1–25.

Frost, R. (1998). Toward a strong phonological theory of visual word recognition: The issues and false trials. *Psychological Bulletin, 123,* 71–99.

Gottlob, L. R., Goldinger, S. D., Stone, G. O., & Van Orden, G. C. (1999). Reading homographs: Orthographic, phonologic, and semantic dynamics. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 561–574.

Grainger, J., & Ferrand, L. (1996). Masked orthographic and phonological priming in visual word recognition and naming: Cross-task comparisons. *Journal of Memory and Language, 35,* 623–647.

Grossberg, S. (1982). *Studies of mind and brain.* Dordrecht, The Netherlands: Reidel.

Grossberg, S., & Stone, G. O. (1986). Neural dynamics of word recognition and recall: Priming, learning, and resonance. *Psychological Review, 93,* 46–74.

Herdman, C. M., LeFevre, J. A., & Greenham, S. L. (1996). Base-word frequency and pseudohomophone naming. *The Quarterly Journal of Experimental Psychology A, 49,*1044–1061.

Kinoshita, S. (2000). The left-to-right nature of the masked onset priming effect in naming. *Psychonomic Bulletin & Review, 7,* 133–141.

Lesch, M. F., & Pollatsek, A. (1993). Automatic access of semantic information by phonological codes in visual word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 19,* 285–294.

Lesch, M. F., & Pollatsek, A. (1998). Evidence for the use of assembled phonology in accessing the meaning of printed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 24,* 573–592.

Locke, J. L. (1978). Phonetic effects in the silent reading of hearing and deaf children, *Cognition, 6,* 175–187.

Lukatela, G., Carello, C., Savic, M., Urosevic, Z., & Turvey, M. T. (1998). When nonwords activate semantics better than words. *Cognition, 68,* B31–B40.

Lukatela, G., Carello, C., & Turvey, M. T. (1990). Phonemic priming by words and pseudowords. *European Journal of Cognitive Psychology, 2,* 375–394.

Lukatela, G., Eaton, T., Lee, C., & Turvey, M. T. (2001). Does visual word identification involve a sub-phonemic level? *Cognition, 78,* B41–B52.

Lukatela, G., Frost, S., & Turvey, M. T. (1998). Phonological priming by masked nonword primes in the lexical decision task. *Journal of Memory and Language, 39,* 666–683.

Lukatela, G., Frost, S., & Turvey, M. T. (1999). Identity priming in English is compromised by phonological ambiguity. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 775–790.

Lukatela, G., & Turvey, M. T. (1994). Visual lexical access is initially phonological: 2. Evidence from phonological priming by homophones and pseudohomophones. *Journal of Experimental Psychology: General, 123,* 331–353.

Lukatela, G., & Turvey, M. T. (1996). Inhibition of naming by rhyming primes. *Perception & Psychophysics, 58,* 823–835.

Lukatela, G., & Turvey, M. T. (1998). Reading in two alphabets. *American Psychologist, 53,* 1057–1072.

Lukatela, G., & Turvey, M. T. (2000). Do spelling variations affect associative and phonological priming by pseudohomophones? *Perception & Psychophysics, 62,* 196–217.

Luo, C. T. (1996). How is word meaning accessed in reading? Evidence from the phonologically mediated interference effect. *Journal of Experimental Psychology: Learning, Memory and Cognition, 22,* 309–323.

McRae, K., Jared, D., & Seidenberg, M. S. (1990). On the role of frequency and lexical access in word naming. *Journal of Memory and Language, 29,* 45–65.

Perfetti, C. A., Zhang, S., & Berent, I. (1992). Reading in English and Chinese: Evidence for a "universal" phonological principle. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 227–248). Amsterdam: North-Holland.

Plaut, D. C., McClleland, J. L., Seidenberg, M. S., & Patterson, K. E. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103,* 56–115.

Raaijmakers, J. G. W., Schrijnemakers, J. M. C., & Gremmen, F. (1999). How to deal with "The language-as-fixed-effect fallacy": Common misconceptions and alternative solutions. *Journal of Memory and Language, 41,* 416–426.

Rastle, K., & Coltheart, M. (1999). Lexical and nonlexical phonological priming in reading aloud. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 461–481.

Rayner, K., Sereno, S. C., Lesch, M. F., & Pollatsek, A. (1995). Phonological codes are automatically activated during reading: Evidence from an eye movement priming paradigm. *Psychological Science, 6,* 26–32.

Rey, A., Ziegler, J. C., & Jacobs, A. M. (2000). Graphemes are perceptual reading units. *Cognition, 75,* B1–B12.

Rouibah, A., Tiberghien, G., & Lupker, S. J. (1999). Phonological and semantic priming: Evidence for task-independent effects. *Memory and Cognition, 27,* 422–437.

Schneider, V. I., Healy, A. F., & Gesi, A. (1991). The role of phonetic processes in letter detection: A reevaluation. *Journal of Memory and Language, 30,* 294–318.

Seidenberg, M. S. (1995). Visual word recognition: An overview. In P. Eimas & J. L. Miller (Eds.), *Handbook of perception and cognition: Speech, language and communication* (pp. 131–179). San Diego, CA: Academic Press.

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological Review, 96,* 523–568.

Seidenberg, M. S., Peterson, A., MacDonald, M. C., & Plaut, D. C. (1996). Pseudohomophone effects and models of word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 48–62.

Van Orden, G. C., & Goldinger, S. D. (1994). Interdependence of form and function in cognitive systems explains perception of printed words. *Journal of Experimental Psychology: Human Perception & Performance, 20,* 1269–1291.

Van Orden, G. C., Johnston, J. C., & Hale, B. L. (1988). Word identification in reading proceeds from spelling to sound to meaning. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 14,* 371–385.

Van Orden, G. C., Pennington, B. F., & Stone, G. O. (1990). Word identification in reading and the promise of subsymbolic psycholinguistics. *Psychological Review, 97,* 488–522.

Xu, B., & Perffeti, C. A. (1999). Nonstrategic, subjective threshold effects in phonemic masking. *Memory and Cognition, 27,* 26–36.

Ziegler, J. C., & Jacobs, A. M. (1995). Phonological information provides early sources of constraint in the processing of letter strings. *Journal of Memory and Language, 34,* 567–593.