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Inhibitory Effects in Form Priming: Evaluating a Phonological Competition Explanation

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Although a majority of studies support the notion that formally similar primes facilitate target processing, recent research has shown inhibition effects in some circumstances, particularly with high-frequency targets. The present studies focused on an explanation of this effect provided by a recent phonological competition model. Lexical decision results using rhyming primes indicate that the inhibition is more prevalent at short stimulus onset asynchronies and is unaffected by requiring verbal report of the prime. Naming results indicate that the inhibition only arises with irregular word pairs. Neither this model nor any of the models considered provided an adequate explanation of these effects. An alternative model that incorporates automatic, lexically based inhibition and strategically based facilitation processes is proposed.

A basic assumption of most models of word recognition is that when a word is identified, a change is produced in the activation levels of the lexical processing structures of formally similar words (Humphreys, Evett, & Quinlan, 1990; McClelland & Rumelhart, 1981; Morton, 1979; Paap, McDonald, Schvaneveldt, & Noel, 1987; Paap, Newsome, McDonald, & Schvaneveldt, 1982; Seidenberg & McClelland, 1989). Yet, finding evidence for this change of activation has been somewhat difficult. For example, using a lexical decision task, Meyer, Schvaneveldt, and Ruddy (1974) reported only a small and nonsignificant facilitation from rhyming primes (i.e., primes that were both orthographically and phonologically similar to their targets). Although subsequent work (Hanson & Fowler, 1987; Hillinger, 1980; Lupker & Williams, 1989; Shulman, Hornak, & Sanders, 1978) has seemed to confirm Meyer et al.'s facilitation effect, failures to observe any effect of rhyming primes have also appeared in the literature (e.g., Martin & Jensen, 1988). Until recently, however, the general consensus has been that the bulk of the data support this basic assumption.

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One possible reason why differing patterns of results have been observed could be that formally similar, and clearly visible, primes do not always produce facilitation. In fact, a series of recent reports suggests that, at least in some circumstances, formally similar primes produce inhibition rather than facilitation (Colombo, 1985, 1986; Grainger, 1990; Henderson, Wallis, & Knight, 1984; Lukatela & Turvey, 1990b; Segui & Grainger, 1990). Most relevant to the present discussion is Colombo's (1986) report that although rhyming primes facilitated low-frequency targets, they inhibited high-frequency targets.

These latter results are not easily accommodated by most current models of word processing. To date, however, three general models have been proposed that seem to be able to account for these inhibition effects. As Colombo (1986) has argued, these results could be interpreted within the framework of McClelland and Rumelhart's (1981) interactive–activation model. Although prime identification is assumed to initially involve the activation of the lexical units of orthographic neighbors, the further assumption can be made that a successful identification also requires the inhibition of strong (and in particular, high-frequency) competitors. The result is that if a high-frequency neighbor is then presented as a target, its processing will be slowed. Low-frequency neighbors do not reach a level of activation that requires them to be inhibited. Hence, whatever activation they receive from prime processing will facilitate their identification if one of them is presented as a target.

More recently, Segui and Grainger (1990) expanded on Colombo's proposal by suggesting that the key to the inhibition may not be the absolute frequency of the target but the relative frequency of prime and target. Specifically, only the neighbors that are actually higher in frequency than the prime need to be inhibited; thus, only these targets should show a delay in processing. The key points to note about these interpretations of the inhibition effect are: (a) they are based on orthographic relationships (although they could be made consistent with a phonological interpretation), (b) the inhibition process should occur whenever the prime is successfully identified, and (c) the effects, both facilitation and inhibition, should occur in all situations requiring target identification. For future reference, this will be referred to as the lexical suppression model.

More recently, two alternative explanations of Colombo's frequency-dependent priming effects have appeared in the literature; both were based (at least in part) on the phonological similarity of prime and target. The first of these (Lukatela and Turvey, 1990b), is primarily based on data from the Serbo-Croatian language, a language with a completely regular correspondence between orthography and phonology. Because of this regularity, it is assumed that identification of a word necessarily occurs through phonological mediation. English, on the other hand, is not a language with extremely regular spelling–sound correspondences. Nonetheless, these authors have recently argued that the principles embodied in the model should also characterize the processing of English words (Lukatela, Lukatela, & Turvey, 1993; Lukatela & Turvey, 1991, 1993).

According to the model, phonologically similar primes produce (a) a phonologically based inhibition effect at the lexical level and (b) a facilitation effect at the sublexical level due to activation of shared sublexical, phoneme units. Colombo's (1986) crossover interaction follows from the fact that the inhibition effect is assumed to be frequency dependent (more inhibition for high-frequency words), whereas the facilitation effect is frequency independent. The key points to note about this model are that (a) the effects are based on phonological rather than orthographic similarity, (b) both lexical inhibition and sublexical facilitation should occur whenever the prime is identified successfully, and (c) inhibition should occur only in tasks requiring lexical involvement. With reference to this final point, Lukatela and Turvey (1990b) demonstrated that the same stimuli that produce inhibition in a lexical decision task produce facilitation in a naming task, a task that, they argue, does not require lexical involvement, at least in Serbo-Croatian.

The second phonologically based model (O'Seaghdha, Dell, Peterson, & Juliano, 1992; Peterson, Dell, & O'Seaghdha, 1989) also has separate facilitation and inhibition components. The facilitation is assumed to be due to activation spreading from sublexical (orthographic and phonological) units to lexical units, producing an increase in activation in the lexical units (or "lemmas") of formally similar words. The inhibition, on the other hand, comes from a competition process that is created by activating the phonological segments of the prime and the target in very close temporal succession.

According to the model, the presentation of the prime causes the creation of both the prime's phonological representation (its phonological segments in the appropriate sequence) and a temporary episodic node that binds together the prime's letter and phoneme nodes. (A word's episodic node is assumed to represent the episodic memory of that word's presentation [Peterson, Dell, & O'Seaghdha, 1989].) When the target shares letters with the prime, target processing tends to increase activation in the prime's lemma and, more importantly, to reactivate the prime's episodic node. *The result is a large increase in all the prime's phoneme units.* Thus, there is an increase in the probability that the phonological code that is ultimately established is actually that of the prime rather than that of the target. If so, target processing is slowed due to the time necessary to resolve the competition this creates and to establish its phonological code. (The assumption would seem to be that, in general, it is necessary to establish the phonological code of the target before an accurate lexical decision can be made.)

The explanation for the inhibition for high-frequency targets and the facilitation for low-frequency targets is based on the time courses of the inhibition and facilitation components. One particularly critical consequence of prime processing is the activation of letter and phoneme units shared by orthographically similar targets, as well as those targets' lemmas. According to the model, this activation decays monotonically; however, as long as there is activation in the nodes, target processing will be facilitated. Inhibition arises whenever the processing of an orthographically similar target reactivates processing units appropriate to the prime to such an extent that the prime's phonological code is reestablished. The potential for this to occur is substantially higher immediately following prime processing because the prime's lemma and phoneme units (specifically the unit it does not share with the target) are highly activated. The result is that high-frequency targets, which are processed more quickly, should be more susceptible to the inhibition component whereas low-frequency targets, which are processed relatively slowly, should be more susceptible to the facilitation component, producing Colombo's crossover interaction. For future reference, this model will be referred to as the phonological competition model.

Experiment 1

The purpose of the present article is to gain a better understanding of the processes involved in form priming through an evaluation of the phonological competition model. (An evaluation of how the other two models can handle the present data will be presented in the General Discussion section.) What differentiates this model from the others is how it characterizes the inhibition and where in the processing sequence it arises. That is, during the selection of the target's phonological segments (and the creation of its phonological code), a competition is caused by the reactivation of the prime's nodes, leading to the recreation of the prime's phonological code. Inhibition is not, therefore, the result of a lowering of activation levels of lexical units occurring before the target's presentation, as in the lexical suppression model or Lukatela and Turvey's (1990b) phonological model. It is this phonological competition process that will be examined in the following experiments.

The probability that a competition situation arises is determined by the extent to which the target can remind the system of its experience with the prime. Two factors would seem to be important. The first factor is the extent to which target processing reactivates the episodic node. Reactivation can only occur if the prime and target share letters. The second factor is the amount of activation left in the system at the time of the target's presentation, particularly the amount of activation left in the prime's lemma and mismatching phoneme node. This activation decays with time unless, presumably, subjects continue to attend to the prime (although this is not specifically stated in the description of the model). Further, since the episodic node represents the episodic memory of the prime, it also seems reasonable to argue that the ability of a given orthographically similar target to reactivate it (which depends on the strengths of the weights linking the letter nodes and the episodic node) also decreases with time. Thus, both factors suggest that the stimulus onset asynchrony (SOA) should be an important determinant of the ultimate effect. Very short SOAs should be more likely to produce inhibition whereas longer SOAs should be relatively free of inhibition.

Three SOA conditions were used in Experiment 1. In order to examine the predictions, what was needed initially was an SOA condition that would clearly show the crossover interaction that Colombo (1986) observed (Experiment 2). To accomplish this, the middle SOA condition (315 ms) was selected to match closely the SOA condition in which Colombo found the crossover interaction. (In order to maintain a parallel with Colombo's experiment, we used rhyming primes and targets.) Also used in Experiment 1 were SOAs of 140 ms and 805 ms. The 140-ms SOA was selected because it seemed long enough to allow the subjects to identify the prime accurately and at the same time the system should be substantially more activated than at 315 ms SOA. If the model is correct, this condition should show less tendency for facilitation for low-frequency targets while maintaining the inhibition for high-frequency targets. The 805-ms SOA was selected because Colombo (1986) demonstrated that there is still some evidence of inhibition up to an SOA of 640 ms, at least with Italian words. If the model is correct, there should be some point at which the inhibition potential is gone while some facilitation potential may still be active. If the 805-ms SOA is long enough to allow the inhibition potential to decay fully, it may, in fact, even be possible to observe facilitation for the more rapidly processed high-frequency words.

Method

Subjects

The subjects were 120 University of Western Ontario undergraduates who received course credit or $6.00 for appearing in this experiment. All subjects were native English speakers and had normal or corrected-to-normal vision.

Stimulus Materials and Equipment

Eighty pairs of rhyming words were selected such that for 40 pairs the second member of each pair had a frequency count higher than 42 per million ($M = 221.8$, Median = 100) and for 40 pairs the second member of each pair had a frequency count of less than 31 per million ($M = 8.8$, Median = 6) (Kucera & Francis, 1967). (Average prime frequencies were 21.5 for the high-frequency targets [Median = 14] and 17.7 for the low-frequency targets [Median = 18].) For each word target, a nonword target was also created by changing the initial letter or consonant bigram.

The primes for both the high- and low-frequency targets were divided into four sets. For any given subject, one of the sets of primes was presented followed by its rhyming word target (the rhyming condition), a second set was presented followed by one of the targets from another prime in its set (the nonrhyming condition), a third set was presented followed by the "rhyming" nonword created from its word target (the nonword-rhyming condition), and the fourth set was presented followed by the nonword created from the word target in the nonrhyming condition. Because each subject saw each target only once, four groups of subjects were required to complete the counterbalancing. (A complete list of the primes, word targets, and nonword targets is presented in Appendix A.)

An IBM PC was programmed to control stimulus presentation and to record and time responses. Primes and targets were presented in uppercase on a Packard Bell monitor (Model PB 1422 EG). Responses were made using the leftmost and rightmost button on a four-button box built for use in reaction time (RT) experiments. The rightmost button was used to indicate a "word" response whereas the leftmost button was used to indicate a "nonword" response. Subjects were required to use their right and left index fingers in responding.

Procedure

Subjects were tested individually. Forty subjects were in each of the SOA conditions (140 ms, 315 ms, and 805 ms). They were told that they would be seeing a series of stimulus pairs and that their task would be to decide whether the second member of each pair was a real English word or not and then to respond by pressing the appropriate button as rapidly and accurately as possible. Subjects first received eight practice trials, containing words and nonwords not used in the main experiment. At this point they were asked if they had any questions and, if not, the main experiment commenced.

Each trial began with a 1400-ms presentation of a fixation dot. The prime followed it after 105 ms and remained on the screen for 105 ms, 280 ms, or 770 ms, depending on the condition. After a 35-ms interstimulus interval (ISI), the target appeared and remained on the screen until the subject responded. The fixation dot for the next trial appeared after an intertrial interval of 1400 ms.

Results

Word Target Trials

Mean RTs. A trial was considered an error if the subject pushed the wrong button or failed to respond within 1600 ms. The overall error rate was 4.0%. In all experiments, these error trials were omitted from the analyses of RTs. The mean correct RTs were submitted to a $3 \times 2 \times 2 \times 4$ (SOA $\times$ Target Frequency $\times$ Rhyme [whether the prime and target rhymed] $\times$ Groups) analysis of variance (ANOVA), with SOA and Groups factors as between-subject factors and the other two factors as within-subject factors. In this and all subsequent experiments, an items analysis was carried out on the mean RTs for the word trials.

Two main effects, SOA ($F[2, 108] = 9.34$, $MS_e = 19965$, $p < .001$ for subjects, $F[2, 288] = 148.24$, $MS_e = 1562$, $p < .001$ for items) and target frequency ($F[1, 108] = 107.07$, $MS_e = 2084$, $p < .001$ for subjects, $F[1, 144] = 23.68$, $MS_e = 10487$, $p < .001$ for items) were significant. These main effects were, however, both qualified by significant interactions with the Rhyme factor (for SOA $\times$ Rhyme, $F[2, 108] = 3.57$, $MS_e = 2257$, $p < .05$ for subjects, $F[2, 288] = 5.80$, $MS_e = 1562$, $p < .005$ for items;

for Target Frequency × Rhyme, $F[1, 108] = 3.94$, $MS_e = 1450$, $p < .05$ for subjects, $F[1, 144] < 1.00$, $MS_e = 10487$, for items) and, more important, the interaction of the three factors ($F[2, 108] = 4.78$, $MS_e = 1450$, $p < .01$ for subjects, $F[2, 288] = 5.36$, $MS_e = 1562$, $p < .01$ for items). The only other effects that even approached significance were the Groups × Target Frequency interaction, $F(2, 108) = 3.06$, $MS_e = 2084$, $p < .05$ for subjects, $F(2, 288) < 1.00$, $MS_e = 10487$, for items) and the Groups × SOA interaction, $F(6, 108) = 2.14$, $MS_e = 19965$, $p < .10$ for subjects, $F(6, 288) = 24.94$, $MS_e = 1562$, $p < .001$ for items. These interactions are due to some groups showing slightly larger frequency or SOA effects than others and, thus, can be attributed to which targets appeared as words for that group. (The others were changed to nonwords for that group.)

The specific predictions of the O'Seaghdha et al. (1992) model suggest that there should be a crossover interaction at the middle SOA, inhibition for high-frequency targets, and no facilitation for low-frequency targets at the short SOA, and only facilitation at the long SOA. Planned comparisons at the 315-ms SOA indicated a significant Target Frequency × Rhyme interaction, $F(1, 36) = 8.12$, $p < .01$, a significant inhibition effect for the high-frequency targets, $t(39) = 2.17$, $p < .05$, one-tailed, and a significant facilitation effect for the low-frequency targets, $t(39) = 1.90$, $p < .05$, one-tailed. Planned comparisons at the 140-ms SOA indicated a significant inhibition effect only for the high-frequency targets, $t(39) = 3.15$, $p < .01$, one-tailed. Planned comparisons at the 805-ms SOA indicated a significant facilitation effect only for the high-frequency targets, $t(39) = 1.91$, $p < .05$, one-tailed. The error rates and mean RTs for Experiment 1 are shown in Table 1.

Errors. The error rates were submitted to the same ANOVA as the RT data. The only significant effects were SOA ($F[2, 108] = 3.24$, $MS_e = .403$, $p < .05$) and target frequency ($F[1, 108] = 12.01$, $MS_e = .434$, $p < .001$). The somewhat marginal SOA effect is due to there being a higher error rate with a 140-ms SOA (5.0%) than with either a 315-ms (3.4%) or 805-ms (3.5%) SOA, although the difference between the 140-ms and 315-ms conditions barely misses significance ($p < .06$) with a Newman-Keuls analysis.

Table 1
Mean Reaction Times (RTs) in Milliseconds and Target Error Percentages in Experiment 1

Target frequency	Rhyming RT	Rhyming Error	Nonrhyming RT	Nonrhyming Error	Facilitation
			140-ms-SOA		
High	529	4.2	503	3.2	−26
Low	565	7.0	559	5.5	−6
			315-ms-SOA		
High	515	2.5	499	1.0	−16
Low	538	5.5	558	4.5	+20
			805-ms-SOA		
High	561	3.0	580	3.5	+19
Low	611	4.2	615	3.2	+4

The frequency effect is due to a slightly lower error rate with high-frequency targets (2.9%) than with low-frequency targets (5.0%). No other main effects or interactions approached significance.

Nonword Target Trials

Mean RTs. Again, a trial was considered an error if the subject pressed the wrong button or produced a latency longer than 1600 ms. The overall error rate was 6.5%. The mean correct RTs were submitted to a 3 × 2 × 4 (SOA × Rhyme × Groups) ANOVA with only the Rhyme factor as a within-subjects factor. All three main effects, SOA ($F[2, 108] = 8.21$, $MS_e = 24813$, $p < .001$), groups ($F[3, 108] = 4.41$, $MS_e = 24813$, $p < .01$) and rhyme ($F[1, 108] = 8.96$, $MS_e = 2275$, $p < .01$) were significant. The groups effect is again a counterbalancing effect due to the nonwords seen by some of the groups being harder to respond to than the nonwords being seen by other groups. The other two effects were qualified by a significant SOA × Rhyme interaction, $F(2, 108) = 7.54$, $MS_e = 2275$, $p < .001$. This interaction is due to the virtual absence of a rhyme effect in either the 140-ms SOA (677 ms vs. 679 ms in the rhyming and nonrhyming conditions, respectively) or the 315-ms SOA (701 ms vs. 703 ms, respectively) conditions, whereas there was a large advantage for rhyming nonword targets in the 805-ms SOA condition (749 ms vs. 801 ms in the rhyming and nonrhyming conditions, respectively). A possible explanation for the pattern of effects for nonwords appears in the General Discussion section.

Errors. The error rates were submitted to the same ANOVA as the RT data. None of the main effects or interactions were significant (all $ps > .05$).

Discussion

The results of Experiment 1 are quite supportive of the predictions of the phonological competition model. At 315-ms SOA, we observed the crossover interaction first reported by Colombo (1986). To our knowledge, this is the first report of this particular result using rhyming word pairs and English stimuli. At the shorter SOA, the inhibition component was slightly stronger, as predicted. That is, high-frequency words showed at least as much inhibition as they did at the 315-ms SOA, whereas the facilitation effect for low-frequency words disappeared and turned into a small, nonsignificant, inhibition effect. At the longer SOA, the inhibition potential seemed to be minimal and there was evidence of a small, but significant, facilitation effect, at least for the high-frequency targets.

Experiment 2

In Experiment 2 we attempted to obtain direct support for the proposal that the inhibition is produced by a phonological competition process. In this task, subjects were required to report the prime verbally on every trial immediately following their response to the target. The SOA used was the same as in the long SOA condition of Experiment 1 (805 ms);

however, it was created by using a short prime-exposure duration (280 ms) and a longer ISI (525 ms). Having this 525-ms blank interval between the prime and target would presumably require subjects to form a stable phonological code for the prime and, thus, keep its processing structures active. In Experiment 1, the 805-ms SOA condition produced only a small facilitation effect, presumably due to the decay of activation in the prime's processing structures, particularly the prime's lemma and the phoneme node for the mismatching phoneme. The expectation in Experiment 2 is that by requiring prime report, these structures will be kept active and, thus, a much stronger tendency for competition (and, hence, for inhibition) will result.

Method

Subjects

The subjects were 24 University of Western Ontario undergraduates who received course credit for appearing in this experiment. All were native English speakers and had normal or corrected-to-normal vision.

Stimulus Material and Equipment

The same stimulus pairs, computer, monitor, and response box were used here as were used in Experiment 1.

Procedure

In Experiment 2, the procedure was essentially identical to the long SOA condition of Experiment 1. The only exceptions were that the subjects were informed that they should verbally report the prime immediately after responding to the target and the prime was exposed for 280 ms followed by a 525-ms ISI. In addition, because of the longer ISI, it was suggested to subjects that they should verbally rehearse the prime during the ISI in order to remember it.

Results

Word Target Trials

Mean RTs. As in the previous experiment, a trial was considered an error if the subject pushed the wrong button or failed to respond before 1600 ms had elapsed. The overall error rate was 5.2%. The mean correct RTs were submitted to a 2 × 2 × 4 (Target Frequency × Rhyme × Groups) ANOVA with Groups as the only between-subjects factor. Both the rhyme main effect ($F[1, 20] = 6.73$, $MS_e = 3831$, $p < .05$ for subjects, $F[1, 144] = 9.42$, $MS_e = 5352$, $p < .01$ for items) and the target frequency main effect ($F[1, 20] = 7.90$, $MS_e = 2053$, $p < .05$ for subjects, $F[1, 144] = 4.91$, $MS_e = 5352$, $p < .05$ for items) were significant. These effects were due to faster responding to high-frequency targets and to targets following a rhyming prime. Also significant in at least one analysis were the groups main effect ($F[3, 20] = 2.97$, $MS_e = 51016$, $p < .10$ for subjects, $F[3, 144] = 52.27$, $MS_e = 5352$, $p < .001$ for items) and the Target Frequency × Groups interaction, $F(3, 20) = 4.55$, $MS_e = 2053$, $p < .05$ for subjects, $F(3, 144) = 1.74$, $MS_e = 5352$, $p < .20$ for items. These effects are again attributable to the counterbalancing manipulation. The error rates and mean RTs for Experiment 2 are shown in Table 2.

Errors. The error rates were submitted to the same ANOVA as the RT data. No main effects or interactions were significant (all *ps* > .05).

Nonword Target Trials

Mean RTs. The error criteria were the same as for the word targets. The overall error rate was 7.4%. The mean correct RTs were submitted to a 2 × 4 (Rhyme × Groups) ANOVA with Groups as a between-subjects factor. The only significant effect was the rhyme effect, $F(1, 20) = 7.00$, $MS_e = 1357$, $p < .05$. This effect was due to faster responding following a rhyming prime ($M = 714$) than following a nonrhyming prime ($M = 742$).

Errors. The error data were submitted to the same ANOVA as the RT data. No main effects or interactions were significant (all *ps* > .05).

Discussion

The expectation in Experiment 2 was that the requirement to report the prime after responding to the target would increase the potential for a phonological competition situation and, hence, increase the tendency for inhibition. The results were quite inconsistent with this expectation. Apparently, the memorial code that is established in order to report the prime not only fails to produce inhibition but, if anything, may enhance the facilitation potential that was evident in the long SOA condition of Experiment 1.

One possible explanation for the failure to obtain inhibition would be that the requirement to report the prime was not a strong enough manipulation to keep the prime's processing structures sufficiently active. In fact, subjects in these tasks were aware that their prime reports were not being timed and, thus, may not have devoted a great deal of capacity to the prime-report task. On the other hand, subjects made virtually no errors in prime report and, without exception, followed the task instructions of reporting the prime immediately after responding to the target. Thus, subjects' behavior suggested that they were certainly devoting processing resources to the task of remembering the prime. As such, there should have been at least some evidence of reduced facilitation effects in comparison to those observed in Experiment 1, if the model and the assumptions underlying this task are correct.

Table 2
Mean Reaction Times (RTs) in Milliseconds and Target Error Percentages in Experiment 2

Target frequency	Condition: Rhyming RT	Rhyming Error	Nonrhyming RT	Nonrhyming Error	Facilitation
High	634	3.3	666	4.6	+32
Low	659	6.7	693	6.3	+34

An alternative explanation for these results would be that subjects were using the SOA interval to create a more stable phonological code for the prime that was then stored in some sort of memory buffer while the prime's processing structures decayed at their normal rates. This type of memory code may be somewhat isolated from (and, therefore, may not interact with) the processes involved in normal word (target) recognition.

Arguing against this explanation, of course, is the fact that the requirement to report the prime actually appeared to enhance the facilitation effects. In terms of the model, this result suggests that the requirement to report the prime does keep active the processing structures shared by the prime and target. Certainly those structures seem to have been much more active here than in the long SOA condition of Experiment 1, which would seem to increase the probability for creating a phonological competition situation. Thus, this explanation provides a somewhat less than ideal reconciliation of the results from Experiment 2 with the phonological competition model.

Experiment 3

Because the results of Experiment 2 provide no direct support for the existence of a phonological competition process per se, the phonological competition model itself was the focus of Experiment 3. This model is a model of word identification; thus, it predicts that the patterns of inhibition and facilitation that arise in a lexical decision task should be mirrored in any task requiring word identification. The task used in Experiment 3 was a naming task, with the same SOAs as used in Experiment 1. As some have argued (e.g., Davelaar, Coltheart, Besner, & Jonasson, 1978; Seidenberg & McClelland, 1989; Seidenberg, Waters, Barnes, & Tanenhaus, 1984), the lexical decision task may not require phonological processing. A naming task, however, does. Thus, failure to find the same pat-terns of inhibition and facilitation as observed in Experiment 1 would be quite problematic for an interpretation of the rhyming inhibition in terms of phonological competition.

At present, there are two reports of inhibition from orthographically and phonologically similar primes in a naming task already in the literature (Grainger, 1990; Peterson, O'Seaghdha, & Dell, 1989). In neither of these studies, however, was a rhyming relationship between prime and target used. Peterson et al. used two-syllable primes and targets that had identical first syllables. Grainger manipulated formal similarity by using primes that differed from the target in only one letter position, a position that varied from stimulus pair to stimulus pair. The questions asked in Experiment 3 were: (a) Do rhyming primes inhibit target naming? and (b) more importantly, Do they produce the same patterns of inhibition and facilitation as a function of SOA and target frequency as observed in the lexical decision task of Experiment 1?

Method

Subjects

The subjects were 120 University of Western Ontario undergraduates who received course credit or $6.00 for appearing in this experiment. All were native English speakers and had normal or corrected-to-normal vision.

Stimulus Materials and Equipment

The 80 prime-target pairs from the previous experiments were also used in Experiment 3. For each subject, half of the targets were paired with a rhyming prime and half were paired with a nonrhyming prime. In order to complete the counterbalancing, four groups of subjects were used.

The computer and monitor were the same as used in the previous experiments. In the present experiment, vocal responses were registered by means of a SHURE (Model 575S) microphone connected to a Lafayette Instruments (Model 18010) voice-activated relay.

Procedure

Again, subjects were tested individually. Subjects were first given a short practice session involving eight stimulus pairs. They were then shown the 80 experimental pairs. They were instructed to name the second stimulus as rapidly and accurately as possible. There were 40 subjects in each of the SOA conditions. Timing parameters were the same as in Experiment 1.

Results

Mean RTs

A trial was scored as an error if the subject stuttered or pronounced the target incorrectly, produced a naming latency longer than 1200 ms or shorter than 200 ms, or did not speak loudly enough to trigger the voice key. (These last two types of error were not included in the error analysis. There were only 108 errors of this nature in the 9,600 trials of this experiment.) Considering only the other types of errors, the overall error rate was 1.5%.

The mean correct RTs were submitted to a 3 × 2 × 2 × 4 (SOA × Target Frequency × Rhyme × Groups) ANOVA. The main effects of SOA ($F[2, 108] = 5.22$, $MS_e = 15740$, $p < .01$ for subjects, $F[2, 608] = 223.71$, $MS_e = 686$, $p < .001$ for items) and target frequency ($F[1, 108] = 208.64$, $MS_e = 259$, $p < .001$ for subjects, $F[1, 304] = 25.85$, $MS_e = 3886$, $p < .001$ for items) were significant in both analyses. The target frequency effect was due to there being shorter latencies with high-frequency targets. A Newman–Keuls analysis of the SOA main effect showed that the 315-ms SOA condition had significantly shorter latencies than either the 140-ms SOA condition ($p < .01$) or the 805-ms SOA condition ($p < .05$). These latter two conditions did not differ significantly. The overall rhyme effect was small and only significant in the subjects analysis, $F(1, 108) = 4.75$, $MS_e = 285$, $p < .05$ for subjects, $F(1, 304) < 1.00$, $MS_e = 3886$ for items. This effect was due to the rhyme condition being slightly faster than the nonrhyme condition. In no instance was there any hint of an inhibition effect. Finally, although there appears to be more evidence of facilitation at the longer SOAs, there was no Rhyme × SOA interaction, $F(2, 108) = 2.10$, $MS_e = 284$, $p > .10$ for subjects, $F(2, 608) < 1.00$, $MS_e = 686$ for items.

The only other significant effects were the groups main effect, $F(3, 108) < 1.00$, $MS_e = 15740$ for subjects, $F(3, 304) = 4.05$, $MS_e = 3886$, $p < .01$ for items, and some interactions involving groups: SOA × Groups, $F(6, 108) < 1.00$, $MS_e = 15740$ for subjects, $F(6, 608) = 26.39$, $MS_e = 686$, $p < .001$ for items; Rhyme × Groups, $F(3, 108) = 5.00$, $MS_e = 285$, $p < .01$ for subjects, $F(3, 304) < 1.00$, $MS_e = 3886$ for items; and Rhyme × Frequency × Groups, $F(3, 108) = 21.46$, $MS_e = 287$, $p < .001$ for subjects, $F(3, 304) = 2.99$, $MS_e = 3886$, $p < .05$ for items. As with all other interactions involving the groups factor, these effects are most likely due to the way words were assigned to the various conditions for the various groups. The error rates and mean RTs from Experiment 3 are shown in Table 3.

Errors

The error rates were submitted to the same ANOVA as the RT data. No main effects or interactions were significant (all *ps* > .05).

Discussion

The results of Experiment 3 clearly indicate that the inhibition effects observed in the lexical decision task of Experiment 1 do not arise in the parallel naming task. As such, these results would seem to be quite problematic for the phonological competition model. In this model, inhibition is accounted for in terms of phonological competition during the selection of the phonological segments for the assembly of the phonological code of the target. Because phonological codes are central to any naming task, this process would definitely be required for correct responding in Experiment 3. The fact that no inhibition was observed would suggest that, at the very least, some of the model's assumptions need to be changed.

Table 3
Mean Reaction Times (RTs) in Milliseconds and Target Error Percentages in Experiment 3

Target frequency	Rhyming RTs	Rhyming Error	Nonrhyming RTs	Nonrhyming Error	Facilitation
	140-ms-SOA				
High	509	1.5	508	1.1	−1
Low	530	0.8	529	0.9	−1
	315-ms-SOA				
High	462	1.3	466	2.1	+4
Low	480	1.6	488	1.4	+8
	805-ms-SOA				
High	491	2.3	491	1.8	0
Low	508	1.3	519	2.4	+11

Experiment 4

One of the important characteristics of the phonological competition model is that word identification (i.e., activation of the target's lemma) is assumed to be required to produce a correct naming response. The results of a number of studies suggest, however, that pronouncing a word can be done without lexical involvement. For example, experimental effects that are dependent on identification of words, like frequency and semantic priming effects, may not appear in a naming task (Baluch & Besner, 1991; Lupker, 1984; Tabossi & Laghi, 1992). Moreover, one of the most widely cited models of reading performance, the so-called "dual-route" model, explicitly assumes the existence of an independent pathway, or processing mechanism, to perform the operation of assembling a pronunciation through the use of sublexical, spelling-sound correspondences, without lexical involvement (Coltheart, 1978; Patterson & Morton, 1985).

The assumption that naming can be performed sublexically raises the possibility that the pattern of results found in Experiment 3 was due to the subjects pronouncing the words simply by assembling sublexical phonological segments. If the presence of inhibition is at least to some extent dependent on the presence of lexical involvement (as the interaction between rhyming and frequency in Experiment 1 suggests), then the pattern of results obtained in Experiment 3 could be explained. Arguing against this explanation, however, is the fact that significant frequency effects were found in Experiment 3, effects that are usually taken as evidence of lexical involvement. Nonetheless, the possibility exists that if subjects could be induced to increase the amount of lexical involvement in word naming, inhibition effects such as those found in Experiment 1 may also be found in a naming task.

It has been claimed that words with irregular spelling–sound correspondences do require lexical identification to be pronounced correctly (Baron, 1977; Coltheart, 1978), although there have been challenges to this claim (e.g., Seidenberg & McClelland, 1989; Van Orden, Pennington, & Stone, 1990). Thus, one way to evaluate the argument in the previous paragraph would be by using rhyming word pairs with irregular spelling–sound correspondences. In fact, the words, both primes and targets, used in Experiment 3 were all short, regular words that could be named accurately by applying subword spelling–sound correspondences. In contrast, Experiment 4 involved the use of 40 rhyming word pairs in which both prime and target shared an irregular spelling–sound correspondence (see Appendix B), that is, a spelling–sound correspondence that is not shared with the majority of words having the same spelling of the rhyming segment. (For example, the pair FLOOD and BLOOD do not rhyme with other words ending in "—ood.") These words will be referred to as the "irregular pairs." They were combined with 40 regular pairs from the previous experiments. According to the above reasoning, the high-frequency, irregular targets should show inhibition. The inclusion of these irregular words in the experiment may also induce more lexical involvement in general, thus possibly producing evidence of inhibition for the regular, high-frequency targets as well.

Method

Subjects

The subjects were 40 University of Western Ontario undergraduates who received course credit for appearing in this experiment. All were native English speakers and had normal or corrected-to-normal vision.

Stimulus Materials and Equipment

Forty prime-target pairs composed of irregular, but rhyming, primes and targets were constructed. Twenty had high-frequency targets (target M = 231.6, target median = 172.5, prime M = 21.4, prime median = 12.0) and 20 had low-frequency targets (target M = 2.5, target median = 2.0, prime M = 21.4, prime median = 11.0). (A list of these pairs is in Appendix B.) These were combined with 40 prime-target pairs from Experiment 3, the 20 with the highest frequency targets (target M = 382.0, target median = 190.0, prime M = 25.8, prime median = 17.0) and the 20 with the lowest frequency targets (target M = 2.2, target median = 2.0, prime M = 13.2, prime median = 9.5) to create 80 pairs. For each subject, half of the targets in each regularity by frequency condition were paired with a rhyming prime and the other half were paired with a nonrhyming prime. To complete the counterbalancing, two groups of subjects were used.

The computer, monitor, microphone, and voice-activated relay were the same as used in Experiment 3.

Procedure

The procedure was the same as in Experiment 3, except that only one SOA (315 ms) was used.

Results

Mean RTs

A trial was scored an error if a subject stuttered, pronounced the target incorrectly, produced a naming latency longer than 1200 ms or shorter than 200 ms, or did not speak loudly enough to trigger the voice key. (Again, these last two types of errors were not included in the error analysis. There were only 66 errors of this type in the 3,200 trials of this experiment.) Considering only the other three types of errors, the overall error rate was 2.2%.

The mean correct RTs were submitted to a 2 × 2 × 2 × 2 (Regularity × Target Frequency × Rhyme × Groups) ANOVA. The main effects of target frequency ($F[1, 38] = 23.55$, $MS_e = 1865$, $p < .001$ for subjects, $F[1, 144] = 11.58$, $MS_e = 1541$, $p < .001$ for items) and regularity ($F[1, 38] = 65.99$, $MS_e = 662$, $p < .001$ for subjects, $F[1, 144] = 19.79$, $MS_e = 1541$, $p < .001$ for items) were significant. The rhyme main effect did not approach significance (both Fs < 1.00) but the Rhyme × Target Frequency interaction was significant in both analyses, $F(1, 38) = 9.34$, $MS_e = 1066$, $p < .01$ for subjects, $F(1, 144) = 4.64$, $MS_e = 1541$, $p < .05$ for items. Also significant in the subjects analysis was the Rhyme × Target Frequency × Regularity interaction, $F(1, 38) = 6.18$, $MS_e = 469$, $p < .05$ for subjects, $F(1, 144) = 1.09$, $MS_e = 1541$, $p > .25$ for items. This interaction was further analyzed through planned comparisons done on the rhyme effect in each of the cells of the Target Frequency × Regularity matrix. Significant inhibition was found for the high-frequency, irregular targets, $t(39) = -2.02$, $p < .05$, but not for the high-frequency, regular targets, $t(39) = -1.24$, $p > .10$. Significant facilitation was found for the low-frequency, irregular targets, $t(39) = 4.52$, $p < .001$, but not for the low-frequency, regular targets, $t(39) = .63$. The only other significant effect was the Target Frequency × Regularity × Groups interaction, $F(1, 38) = 6.24$, $MS_e = 513$, $p < .05$ for subjects, $F(1, 144) < 1.00$, $MS_e = 1541$ for items. As before, this interaction was most likely due to the counterbalancing procedure. The error rates and mean RTs for Experiment 4 are shown in Table 4.

Errors

The error rates were submitted to the same ANOVA as the RT data. The main effects of Target Frequency, $F(1, 38) = 14.32$, $MS_e = .171$, $p < .001$, and Regularity, $F(1, 38) = 55.29$, $MS_e = .190$, $p < .001$, as well as their interaction $F(1, 38) = 20.79$, $MS_e = .154$, $p < .001$, were significant. These effects are due to the fact that the regularity effect was somewhat larger for low-frequency words. Also significant was the groups effect, $F(1, 38) = 8.30$, $MS_e = .182$, $p < .01$, and the Groups × Target Frequency, $F(1, 38) = 4.68$, $MS_e = .171$, $p < .05$, and the Groups × Regularity interactions, $F(1, 38) = 7.96$, $MS_e = .190$, $p < .01$. The effects were again presumed to be due to the counterbalancing procedure.

Discussion

Irregular word pairs were included in Experiment 4 to induce subjects to complete lexical identification of at least those words in the process of producing their names. The most important result is that the pattern of interaction between frequency and rhyming obtained in lexical decision was replicated in a naming task for these word pairs. High-frequency, irregular targets produced a significant 12-ms inhibition effect, whereas low-frequency, irregular targets produced a 23-ms facilitation effect. Of interest is that high-frequency, regular targets also produced at least a bit of evidence of inhibition for the first time (a small but nonsignificant 7-ms inhibition effect).

The results of Experiment 4 are then partially consistent with the interpretation of the Target Frequency × Rhyme

Table 4
Mean Reaction Times (RTs) in Milliseconds and Target Error Percentages in Experiment 4

Target frequency and regularity	Rhyming RTs	Rhyming Error	Nonrhyming RTs	Nonrhyming Error	Facilitation
High, irregular	522	1.8	510	1.0	−12
High, regular	500	0.5	493	0.0	−7
Low, irregular	532	2.5	555	3.4	+23
Low, regular	514	0.1	518	0.1	+4

interaction given by the phonological competition model. That is, the irregular word data are consistent with a phonological basis for inhibition effects in both naming and lexical decision tasks. In the naming task the phonological representation of words must necessarily be retrieved. In the lexical decision task, although processing can presumably be based on orthographic codes (Seidenberg & McClelland, 1989), automatically activated phonological codes are likely to enter into the decision process. Thus, in both tasks a phonological component seems to be involved to some extent. The existence of inhibition in both tasks then provides some evidence for the phonological competition model's explanation in terms of competition during the selection of the phonological segments of the target.

What is not consistent with the model is that the inhibition effect of a rhyming prime can be seen only with irregular words. If the inhibition effect arises simply because of a competition during the selection of phonological segments due to a reactivation of the prime's phonological representation, then the effect should be independent of how the phonological representation of the target word is being constructed. Moreover, if the facilitation effect is due to increased activation in nodes shared by the prime and target (as well as activation in the target's lemma), then the facilitation should be found in the naming task with regular words as well as with irregular words. Thus, although the model could probably be modified to account for the results (along the line of the arguments presented in the introduction to Experiment 4), it cannot do so in its present form.

General Discussion

Until recently, the general assumption has been that the effects of a formally similar prime were much the same as the effects of a semantically similar prime, that is, a general facilitation of target processing. However, recent evidence (Colombo, 1985, 1986; Grainger, 1990; Henderson et al., 1984; Lukatela & Turvey, 1990b; Segui & Grainger, 1990) suggests that the effects of a formally similar, but clearly visible, prime can also be inhibitory. The purpose of the present studies was to gain a better understanding of the factors and processes involved in these effects. The results obtained here define some of the conditions under which inhibition and facilitation effects occur, suggesting some conclusions about the nature of these processes.

First, the present data show that inhibition in a lexical decision task is tied to the onset asynchrony between prime and target, occurring more rapidly than facilitation and also decaying somewhat sooner. Second, requiring subjects to report the prime does not enhance the inhibition effects, although it may enhance the facilitation with a long SOA. Third, the inhibition effect and, possibly, the facilitation effect appear to depend on the involvement of a lexical code during target processing. Evidence for this comes first from the fact that both effects do occur in lexical decision, where the task requires an evaluation of whether a given code is lexically defined. In addition, although no effect occurs when naming can be performed on the basis of sublexical codes, the effects become apparent when naming is likely to involve a lexical code, as when words with irregular pronunciations are used.

Our interpretation of the present results will involve consideration of a number of issues. First, we consider whether either the lexical suppression model or the Lukatela and Turvey (1990b) model can provide an adequate account of the present data. We then present what seem to be more viable alternative explanations. In this discussion one issue that will be considered is whether the origin of the effects lies at the level of orthography, phonology, or both. A related issue is whether the pattern of results obtained for lexical decision and naming tasks reflect the same type of process. Given that the processes required in lexical decision and naming are only partially overlapping, it is certainly possible that different mechanisms may be responsible for the effects in the two tasks. Finally, at a more global level there is the issue of the relation of the present data to the results obtained with masked priming and the implications for form priming and word recognition in general.

The Lexical Suppression Model and the Lukatela and Turvey (1990b) Model

As noted, the phonological competition model in its current form can not account for the entire set of data presented here. In trying to give an account for these data we should first evaluate the other two models mentioned before considering other possible alternatives.

In the lexical suppression model, lexical activation is the source of both the inhibition and facilitation effects. The degree of activation in a target is essentially a function of the frequency relationship between the prime and target, although it would certainly be possible to argue that time is important as well. That is, it could be assumed that this activation decays to its baseline level as a function of time. The implication for Experiment 1 is that if the pattern does change as a function of SOA, the strongest crossover interaction should have been at the shortest SOA rather than at the middle SOA. Further, the model can not easily be extended to predict inhibition turning into facilitation (as happened with the high-frequency targets) as SOA increases. Thus, the model is quite inconsistent with the data from Experiment 1. Further, because the model is a model of word identification, it predicts that whatever effects are found in a lexical decision task would also be found in a naming task. As such, the model is also inconsistent with the data from Experiment 3. Thus, although it might be possible to make the model consistent with the data from some of the present experiments, in its current form it can not provide an adequate account of most of the present results.

In Lukatela and Turvey's (1990b) model, the inhibition effect is due to inhibition of lexical nodes, whereas the facilitation effect is due to facilitation of sublexical, phonological processing. To account for the data from Experiments 1 and 2, the model would have to assume that lexical inhibition is very strong at the shorter SOAs but decays fairly rapidly. It would also have to assume that sublexical activation is maintained for a much longer period of time. These assumptions, however, would seem to be somewhat problematic. Because it is the sublexical activation that produces changes in lexical activation, the pattern of lexical activation or inhibition should be maintained as long as sublexical activation exists to maintain it. Only when the sublexical activation disappears should the lexical activation or inhibition also disappear. With respect to Experiment 3, the model predicts that all targets would show facilitation, since they would all benefit from sublexical processing structures activated by the prime. This prediction is also clearly inconsistent with the data. Finally, in Experiment 4 both high- and low-frequency irregular targets should show less facilitation than the regular targets because they require lexical access and, hence, can be exposed to lexical inhibition. Although this was the case for the high-frequency targets, it was not for the low-frequency targets, which showed much more facilitation than their regular counterparts. Thus, this model also can not provide an adequate explanation of the pattern of data reported here.

Conditions That Create the Inhibition and Facilitation

The main issue that must be addressed by models of form priming from visible primes is: What is the mechanism or mechanisms that produce the facilitation and inhibition effects? Particularly important in attempting to determine the source of the effects is an analysis of the conditions that create inhibition and facilitation. Inhibition is found only when primes are clearly visible, but at short SOAs and with high-frequency target words, that is, under conditions in which prime processing may not be fully complete before target processing has reached an advanced stage. Moreover, it occurs when some type of lexical involvement is required. This pattern of conditions suggests that the inhibition arises out of Stroop-like, automatic processes.

Facilitation effects in form priming experiments seem to arise in two different temporal conditions. Experiments involving short exposures and masked primes do typically show facilitation effects (Evett & Humphreys, 1981; Forster, 1987; Forster, Davis, Schoknecht, & Carter, 1987; Humphreys et al., 1990; Humphreys, Evett, Quinlan, & Besner, 1987; Humphreys, Evett, & Taylor, 1982; Lukatela & Turvey, 1990a; Perfetti, Bell, & Delaney, 1988). These effects are typically explained in terms of preactivation of sublexical (or lexical) processing structures shared by the prime and target. On the other hand, when the prime is unmasked and clearly visible, facilitation emerges more clearly either with low-frequency words, which presumably take longer to process, or at longer SOAs. In other words, for visible primes, facilitation is observed when the codes for prime and target are easier to keep separate. Moreover, in the present experiments, facilitation effects for nonwords were also found at long SOAs. Such effects would not be easily explained just in terms of preactivation of letter units shared by prime and target, considering that they arise only at long SOAs. Thus, the facilitation with unmasked primes is more likely to be due to a nonautomatic mechanism, a mechanism that is different than the mechanism that produces the facilitation with masked primes.

Further support for this argument comes from the essential lack of priming when naming regular words. Even if it is assumed that these words are named without lexical involvement, it is still the case that primes must activate the sublexical orthographic and phonological units of formally similar targets. Thus, if sublexical activation were the source of the facilitation effects, one would expect that the processing of these words should be facilitated even in a naming task. Note that if the lack of facilitation were due to sublexical activation dying off quickly, then the same source certainly could not be producing facilitation at long SOAs. These considerations also make it unlikely that facilitation effects observed in form priming could all be due to the same source. Further, because the facilitation effects with visible primes do not appear to be automatic, it also appears that they have a different source than the inhibition effects from these same primes.

Related to the question of the conditions under which inhibition and facilitation arise is that of whether the effects arise at the orthographic or phonological level. We have suggested that although the inhibition was explained in terms of orthographic relationships in the lexical suppression model (at least in the original form; Colombo, 1986), it could have just as easily been based on phonological relationships. The interaction between rhyming, regularity, and frequency in Experiment 4 (or, in other words, the fact that the effects produced by rhyming differ depending on a phonological factor, regularity) does suggest that phonological codes may be involved in the process. We now present a model in which the inhibition and facilitation from visible primes are due to different sources.

A Proposed Explanation of Form Priming From Visible Primes

The Facilitation Effect

The basic argument is that facilitation with visible primes is not automatic but is due to strategy-driven, controlled processes. Such processes would, presumably, be recruited to aid processing specifically when the phonological nature of the target can be predicted with some certainty. Consider, for example, the situation in Experiment 4. Under normal circumstances, the sublexical, phonological processing of irregular words produces an incorrect phonological code. Priming these words with a prime that shares the target's irregularity may bias the sublexical mechanism that is responsible for the spelling–sound translation process toward the correct phonological code of the rhyming segment. Then subjects would only need to change the first consonant to allow them to produce the correct response without lexical involvement. The result would be a priming effect for irregular words due to sublexical rather than lexical processing. Note as well, however, that this would be much more likely to be the case with the more slowly processed, low-frequency targets. The pronunciation of high-frequency targets is instead more likely to be lexically driven, thus making them susceptible to the influence of lexically based inhibition.

The explanation of the facilitation effect in the lexical decision experiments would be based on a slightly different use of the prime. When a rhyming target is presented, the repetition of the rhyming segment would make the completion of the target's phonological code relatively fast, allowing the evaluation of its lexical status to begin rapidly at both phonological and orthographic levels. If the time necessary to create the target's phonological code in this fashion yields a lexical identification before the output of the orthographic processing route, the result would be a facilitation effect. Factors that can be important here are the SOA and the target's frequency. The SOA is important because completing the target's phonological code in this way would first require a fairly well established phonological code from the prime. To the extent that the SOA is short, the prime's phonological code will be available later in target processing and, thus, lose its ability to aid target processing. Similarly, the target's frequency is important because it will determine the speed of the orthographic processing. Orthographic processing of high-frequency words will be so rapid that they would only benefit from this alternative route at longer SOAs when the prime's code is firmly established and, thus, can have its strongest effect.

The account of facilitation that has been proposed also has implications for the nonword data from these experiments. Phonological codes for nonwords can, presumably, also be established more quickly when the spelling pattern of the rhyming segment is repeated, allowing the process of evaluating their lexical status to begin more rapidly than for nonrhyming nonwords. If so, the result would be a facilitation effect for the rhyming nonwords. As argued, because time is required to form a useful phonological code for the prime, the two long SOA conditions in Experiments 1 and 2 should be those in which these types of phonological effects should be most apparent. Indeed, these two conditions showed significant facilitation effects for the rhyming nonwords as well as for the more rapidly processed high-frequency words. In contrast, the other two SOA conditions in Experiment 1 showed no evidence of a nonword facilitation effect.

An implication of this proposal is that because the facilitation effect is strategy driven, facilitation may vary as a function of the type of formal relationship between prime and target. In fact, rhyming may be the relationship that is, in general, most likely to produce facilitation effects (Bowey, 1990). Lukatela and Turvey (1990b), for example, reported reliable inhibition for high-frequency targets and little facilitation for low-frequency targets when the five-letter primes and targets differed at the third or fifth position. When targets differed at the first position from their primes (and, hence, rhymed with them) there was little evidence of inhibition for high-frequency targets and significant facilitation for low-frequency targets. Segui and Grainger (1990) found strong inhibition effects for high-frequency targets but little evidence of facilitation for low-frequency targets when primes and targets differed at a single (but unpredictable) letter position. Colombo (1986, Experiment 3) reported a similar set of results when the related primes and targets shared the first two or three letters. In all of these experiments the SOA was at least as long as the middle-range SOA used here, suggesting that subjects had, in principle, sufficient time to implement a processing routine that could have aided the processing of low-frequency words. The fact that they didn't suggests that this type of routine is easier or more likely to be implemented for rhyming pairs than for any other type of formal relationship.

The preceding account is an attempt to explain the facilitation effect with visible primes. As noted, a review of the form priming literature with masked primes seems to indicate that inhibition does not arise when care is taken to make sure that subjects can not identify the prime (Evett & Humphreys, 1981; Forster, 1987; Forster & Davis, 1984, 1991; Forster et al., 1987; Humphreys et al., 1982; Humphreys et al., 1987; Lukatela & Turvey, 1990a; Perfetti et al., 1988; Peterson, O'Seaghdha & Dell, 1989, although see Segui & Grainger, 1990). Rather, the typical result is facilitation. Given that our explanation of the facilitation effect with visible primes is based on a strategic use of the prime, it would not be a suitable explanation of these facilitation effects. The implication is that the facilitation effects with masked primes must have a different locus.

In general, models based on activation spreading (e.g., McClelland & Rumelhart, 1981; Paap et al., 1982) predict an early locus of facilitation in situations when the prime is masked. After a word is presented but prior to its identification, the activation levels of nodes for orthographically similar words are raised due to activation feeding in from shared sublexical (letter) units. If a prime is masked so that processing is disrupted before the word can be uniquely identified, these units would still be active and facilitation would be expected. Visible primes, on the other hand, would be uniquely identified. Thus, when the prime is not masked, the pattern of activation in the system may be quite different than when it is masked. In particular, sublexical activation may dissipate quickly as it becomes completely swamped by the lexical inhibition process.

The Inhibition Effect

So far we have explored mainly the characteristics of the facilitation effect. As regards inhibition, one possibility is that it is due to a suppression mechanism operating on the lexical nodes of orthographic neighbors. Such a mechanism is specifically built-in to the interactive–activation model (McClelland & Rumelhart, 1981); thus, this model would seem to be a prime candidate for explaining the present effects. As currently formulated, however, the model cannot explain our pattern of results. The basic problem is that the inhibition is not specifically directed to orthographic neighbors but to all other word nodes. Consequently, the inhibition that derives from prime processing is much more detrimental to orthographically dissimilar words than to orthographically similar words, because the latter receive activation as well as inhibition from the prime presentation. Thus, when prime processing is complete, the nodes for orthographically similar words would generally tend to be more activated than the nodes for dissimilar words, producing a facilitation effect, rather than an inhibition effect, for orthographic neighbors.

This is exactly the result obtained with masked primes but not the result obtained with visible primes.

A change in the parameters or assumptions of the model would probably allow it to account for the present results, in particular, the result that only high-frequency neighbors show inhibition. These assumptions, however, would be entirely ad hoc, made only for the purposes of accounting for the present data. What would also seem to be necessary would be the theoretical motivation for making changes of this nature. As has been noted elsewhere (Colombo, 1986), one such motivation could be the necessity of having a selection mechanism that operates, when the words are clearly visible, on activated units that have very similar activation levels, that is, a mechanism that selects from among a set of orthographically similar words. Further experimentation may clarify whether this type of mechanism actually exists and, if so, the conditions under which it operates.

As an alternative, the inhibition could be conceptualized within the framework of the activation–verification model (Paap et al., 1987; Paap et al., 1982). In this model, lexical access is accomplished by means of a serial search of a set of candidate words orthographically similar to a presented word (referred to as the "verification" process). The candidate set is ordered in terms of frequency so that higher frequency words are evaluated earlier. As Segui and Grainger (1990) suggested, it could be assumed that after a word has been evaluated and rejected it will be in a state of lowered activation for a period of time so that it would be less likely to be included in a subsequent verification set.

In terms of the present paradigm, the implication is that the process of identifying the prime would involve the creation of a verification set and the subsequent rejection of orthographically similar words with higher frequencies. When one of these orthographically similar, high-frequency words is then presented as a target, it will be less available to the verification process than when it follows a dissimilar prime. The result will be an inhibition effect. Targets with lower frequencies are much less likely to be evaluated and rejected during the verification process. Thus, they should be much less likely to show inhibition effects. One thing that should be pointed out is that the model in its most recent version (Paap, Noel, & Johansen, 1992) also incorporates the idea that regular words can be named by application of spelling–sound correspondence rules without requiring this verification process. Thus, the model also accounts for the lack of inhibition in Experiment 3.

Both accounts of inhibition described up to this point are orthographically driven. There is also an alternative, phonologically driven account of the inhibition effect. The idea is that shortly after presentation of a stimulus word, there is considerable noise in the system created by the simultaneous and automatic activation of a number of phonological codes (Shallice & McCarthy, 1985; Van Orden et al., 1990). The availability (activation level) of the codes depends on the nature of the orthographic neighborhood, reflecting the number and frequency of orthographic neighbors. Some sort of selection mechanism must then operate on these activated codes. In general, so-called "regular" correspondences (i.e., phonological correspondences present in large numbers of neighbors) interfere with irregular, lexically derived codes. This interference may be exacerbated when a rhyming prime precedes a high-frequency irregular target because of the additional emphasis that rhyming primes place on sublexical correspondences in general. That is, for high-frequency irregular words, word-specific phonological codes would be available relatively soon and would normally drive the naming process. If the use of rhyming primes does indeed produce an enhancement of the sublexical codes for the rhyme component and if those codes (both regular and, because of the prime, irregular) are activated simultaneously with the lexically derived code, the system might enter into a maximally noisy state. Thus, selecting from among the codes would be quite difficult, producing the inhibition observed in Experiment 4.

This interpretation suggests that an important indicator of whether effects will be seen is the absolute RT for a specific task and situation. Indeed, longer naming times were obtained in Experiment 4, as compared to Experiment 3, even for the same regular words. This lengthening of RTs suggests that the experimental situation was more complex, possibly because several types of codes entered into the computation of the correct phonological code. For instance, it could be that when only regular words are presented (Experiment 3), the system focuses specifically on the process of assembling sublexical codes. When a lexical code is often necessary (Experiment 4), the selection process has to operate on both lexical and sublexical codes. An additional prediction is that any unrelated prime condition would show some inhibition when compared with a neutral prime condition. The reason is simply that any prime will activate a set of codes that must be rejected in the selection process.

A similar explanation can be applied to the lexical decision results even though only regular words were used. Because the nature of the task requires the decision to be based on the lexical status of the letter string presented, the conditions are somewhat similar to those that lead to inhibition in the irregular word condition of the naming task. The underlying assumption would be once again that the rhyming manipulation enhances the availability of phonological codes, thus making it more likely that the decision process is based on phonological, rather than orthographic, codes. In the case of lexical decision, however, the evidence supporting a phonological basis of the interference is less compelling than in the naming task. Thus, while further experimental evidence needs to be brought to bear on this issue, any single-source account of the results of the two tasks would be preferred on the basis of theoretical economy.

In summary, a number of possible mechanisms of the inhibition effect have been offered. According to the first two, inhibition is due to the normal interactions in the lexical system when a word is successfully identified (Colombo, 1986; Segui & Grainger, 1990). This process could be thought of as analogous to the inhibition processes in the interactive–activation model or an inhibition process that arises out of a rejection during the verification process. According to the other account, inhibition effects would reflect the state of the system in a situation that has been exacerbated by the rhyming prime but which, to some extent, is normally created when phonological codes become simultaneously active shortly after reading a word. Facilitation from visible primes, on the other hand, is argued to reflect adaptation to the specific aspects of an experimental context.

The purpose of the present article was to investigate a somewhat counterintuitive finding, that under some circumstances, target processing can be inhibited by formally similar primes. The results posed serious problems for all the existing models, including the model that formed the main focus for the discussion, the phonological competition model (O'Seaghdha et al., 1992). Three possible alternative accounts of the inhibition have been proposed. As argued, although the characteristics of the rhyme priming manipulation certainly make more salient some of the processes involved, all accounts are to some extent reflective of the normal interactions that go on during lexical processing. Future research using form priming with visible primes should help us to gain a better understanding of the nature of those interactions.

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Appendix A

Rhyming Word (and Nonword) Pairs Used in Experiments 1–3

High-Frequency Targets		Low-Frequency Targets	
ANT–PLANT(BLANT)	BAT–HAT(DAT)	BEER–DEER(FLEER)	APE–GRAPE(TRAPE)
ARM–FARM(GARM)	CAGE–PAGE(VAGE)	BRIDE–SLIDE(GRIDE)	BENCH–WRENCH(CRENCH)
BEET–FEET(LEET)	CAKE–SNAKE(GLAKE)	BUG–JUG(PRUG)	BIB–CRIB(PIB)
BREAD–HEAD(GLEAD)	CAVE–WAVE(TRAVE)	DOVE–GLOVE(FLOVE)	CHIN–FIN(PLIN)
CANE–PLANE(FANE)	CHAIN–TRAIN(PRAIN)	EAR–GEAR(MEAR)	COUCH–POUCH(LOUCH)
CLAW–SAW(TAW)	CLOCK–BLOCK(TROCK)	FISH–DISH(MISH)	CROWN–CLOWN(TROWN)
CHAIR–HAIR(GAIR)	DUCK–TRUCK(NUCK)	FLOWER–TOWER(DOWER)	DART–CART(BLART)
FAN–CAN(CRAN)	FLAG–BAG(KAG)	CORN–HORN(FLORN)	DRUM–PLUM(TRUM)
FLOOD–BLOOD(SLOOD)	FOX–BOX(GOX)	HUT–NUT(LUT)	GATE–SKATE(VATE)
HOOK–BOOK(MOOK)	GOAT–BOAT(FLOAT)	KNEE–BEE(GREE)	LOG–FROG(MOG)
MOUSE–HOUSE(COUSE)	PEACH–BEACH(MEACH)	LAMP–STAMP(FRAMP)	LOOM–BROOM(TROOM)
PAN–MAN(HAN)	PEAR–BEAR(TREAR)	MICE–DICE(FICE)	CAT–MAT(GRAT)
SLED–BED(VED)	BONE–PHONE(GLONE)	MOUNTAIN–FOUNTAIN(LOUNTAIN)	NAIL–SNAIL(KAIL)
STAR–CAR(NAR)	TORCH–PORCH(WORCH)	NURSE–PURSE(SURCE)	NEST–VEST(DEST)
SUN–GUN(MUN)	NOSE–ROSE(BOSE)	POT–DOT(VOT)	NOOSE–MOOSE(FOOSE)
TACK–BACK(DACK)	RAKE–LAKE(PAKE)	ROOTS–BOOTS(GLOOTS)	TAIL–PAIL(LAIL)
TENT–CENT(NENT)	SPOON–MOON(DROON)	SHELL–BELL(DRELL)	PARROT–CARROT(HARROT)
TIRE–FIRE(NIRE)	SWING–RING(FLING)	SHEEP–JEEP(DREEP)	PIG–TWIG(LIG)
TOOL–POOL(DOOL)	WHIP–SHIP(MIP)	STORK–FORK(VORK)	ROCKET–LOCKET(VOCKET)
TOY–BOY(MOY)	WING–KING(GLING)	TIE–PIE(KIE)	TRUNK–SKUNK(NUNK)

Note. Pairs in Columns 1 and 4 were also used in Experiment 4.

Appendix B

Rhyming Word Pairs Used in Experiment 4

High-Frequency Targets			
CALF–HALF	DREAD–HEAD	COUTH–YOUTH	LOSE–WHOSE
TON–SON	PROVE–MOVE	FLOOD–BLOOD	STALK–WALK
POUR–FOUR	BREAD–DEAD	GUILD–BUILD	THREAD–SPREAD
CROUP–GROUP	QUOTH–BOTH	BALK–TALK	FREIGHT–WEIGHT
GUILT–BUILT	STEAK–BREAK	NONE–DONE	DOUGH–THOUGH
Low-Frequency Targets			
VOGUE–ROGUE	WASH–SQUASH	LEARN–YEARN	WEIGH–SLEIGH
BOURN–MOURN	GLOVE–SHOVE	COARSE–HOARSE	WART–QUART
FAULT–VAULT	HEIGHT–SLEIGHT	TOMB–WOMB	COUGH–TROUGH
FOOT–SOOT	VAGUE–PLAGUE	TIER–PIER	THUMB–NUMB
VEIN–REIN	EARL–PEARL	FOLK–YOLK	FRAUD–LAUD

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