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Revisiting Bias Effects in Word-Initial Phonological Priming

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The phonological priming paradigm, in which participants respond to the second of 2 consecutively presented spoken words, has the potential to be a useful tool with which to study lexical processing. Concerns about response biases distorting the results have persisted since its introduction. This study explored the manifestation of biases by modifying the standard priming experiment such that the magnitude of priming effects using the same items could be compared at different points during the testing session. Four experiments investigated whether a recent dissociation of response biases and priming effects is evidence of lexical inhibition when the prime and target overlap by the first 3 word-initial phonemes (M. Hamburger & L. M. Slowiaczek, 1996). Biases were found in conditions previously thought to prevent their influence.

Priming methodologies, such as semantic priming and form priming (Forster, 1998; Neely, 1991; Zwitserlood, 1996), are a mainstay of researchers in cognition and are used in a variety of ways to learn about the structural and processing characteristics of memory. In the field of spoken word perception, one type of form priming that has been of considerable interest is phonological priming. Two words (prime and target) are presented auditorily in (usually) close temporal succession, and participants perform a task on the second word (e.g., lexical decision or naming). The number of phonemes that the prime and target share at the same positions in the words and the locations of these overlapping phonemes (word initial, *boat–buck*, or word final, *cat–dot*) are the most frequently manipulated variables. Of interest is what effect hearing the prime has on processing the target.

Phonological priming has been used to explore theoretical issues, such as the nature of sublexical and lexical representations that the recognition system computes (Radeau, Morais, & Dewier, 1989; Slowiaczek, McQueen, Soltano, & Lynch, 2000), and to explore the lexical mechanisms involved in recognition (Slowiaczek & Pisoni, 1986), such as whether activated lexical candidates compete for recognition by inhibiting one another. This latter issue has received a great deal of attention in the literature, because an answer will help researchers to understand how a single lexical entry is selected among its competitors (Luce & Pisoni, 1998; Marslen-Wilson, 1987; McClelland & Elman, 1986; Norris, McQueen, & Cutler, 2000).

Since Slowiaczek and Pisoni (1986) first used phonological priming to study lexical mechanisms, researchers have been concerned about whether the data from such experiments provide an accurate picture of lexical processing or whether they are distorted by response biases that participants develop after noticing the phoneme overlap between prime and target (Goldinger, Luce, Pisoni, & Marcario, 1992; Radeau et al., 1989). In particular, participants might use information about the prime to aid in responding to the target, especially if they think it will improve task performance. Concerns about response biases have been sufficiently great that much of the literature has focused on dissociating effects due to response bias from those due to lexical processes. The present study continues in this vein.

Despite the fact that the issue of response biases has been addressed for over a decade, there is still disagreement between those who believe the paradigm can tell us something useful about lexical processing and those who have severe doubts (see Radeau, Morais, & Segui, 1995, for a review). One ongoing debate has focused on the interpretation of an intriguing pattern of response time (RT) data obtained using monosyllabic primes and targets. In a series of single-word shadowing experiments in which participants named the target quickly, Slowiaczek and Hamburger (1992) found that primes that had one phoneme overlapping with the target (a 1-overlap prime; e.g., *slip* [prime] and *snack* [target]) or two phonemes overlapping with the target (a 2-overlap prime; e.g., *snip* [prime] and *snack* [target]) produced shorter naming times to the target than did a 0-overlap, unrelated prime (e.g., *plight*). A 3-overlap prime (e.g., *snap*), however, caused a slowdown in naming relative to the 0-overlap condition.

Slowiaczek and Hamburger (1992) interpreted these data as consistent with an interactive-activation account of word recognition (see, e.g., Columbo, 1986; McClelland & Elman, 1986). The change from an RT advantage in the 1- and 2-overlap conditions to an RT disadvantage in the 3-overlap condition was the result of priming effects switching from facilitation to inhibition as overlap increased. With one or two overlapping phonemes, lexical representations are primed sufficiently to raise their activation levels to aid recognition of the target but not enough to cause a measurable amount of inhibition between lexical entries. With three overlapping phonemes between prime and target, lexical candidates are

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activated enough to inhibit one another, which causes the slowdown in responses to the target.

In two studies using multiple tasks but not shadowing, Goldinger et al. (1992; see also Goldinger, 1998) found converging evidence that the RT advantage in the 1- and 2-overlap conditions is due to response bias. One of the most convincing demonstrations of this came from a series of lexical decision experiments in which the interstimulus interval (ISI) between prime and target and the percentage of trials on which the prime and target were phonologically related (PRP) were varied, two manipulations effective in past work at reducing the influence of response biases (Neely, 1977, 1991; Posner & Snyder, 1975). The prime and target overlapped by only the initial phoneme (e.g., *slip–snack*). When the PRP was 80% and the ISI was 500 ms, RTs were facilitated, just as Slowiaczek and Hamburger (1992) found. When the PRP was reduced to 10% and the ISI was shortened to 50 ms, responses to these same stimuli slowed, which was suggestive of lexical inhibition. Goldinger et al. (1992) obtained a similar outcome when participants had to identify the target that was embedded in noise.

Hamburger and Slowiaczek (1996) argued that the response bias account of Goldinger et al. (1992), who used only 1-overlap prime–target pairs, might not generalize to 3-overlap word pairs. This is because the results are opposite in the 1- and 3-overlap conditions: The former yielded a response speed-up, whereas the latter produced a response slowdown. Instead, Hamburger and Slowiaczek suggested these opposite outcomes reflected the operation of different processes: the former, response bias, and the latter, lexical inhibition. To make their point, Hamburger and Slowiaczek attempted to dissociate the two effects and show that the 3-overlap slowdown was unaffected by response bias.

Hamburger and Slowiaczek (1996) reran Experiment 2a of Slowiaczek and Hamburger (1992) twice, manipulating ISI and PRP across experiments to alter expectations about the relationship between prime and target, as in Goldinger et al. (1992). Expectations of overlap were set high in Experiment 1 through the use of a PRP of 75% and an ISI of 500 ms. Response biases were predicted to emerge in the form of an RT advantage in the 1- and 2-overlap conditions. Not only did Hamburger and Slowiaczek (1996) find this RT advantage, but no response slowdown emerged in the 3-overlap condition. Experiment 2 was designed to minimize response biases by lowering expectancies about phoneme overlap. The PRP was reduced to 21%, and the ISI was shortened to 50 ms. There were no reliable facilitatory effects in the 1- and 2-overlap conditions, suggesting biases were eliminated, but there was a 36-ms slowdown in the 3-overlap condition.

Hamburger and Slowiaczek (1996) interpreted the latter result as evidence of lexical inhibition. Their reasoning was based on the opposite effects that the expectancy (i.e., PRP and ISI) manipulations had on responding. In the high-expectancy experiment, in which response biases should have been present, no inhibition was found. In the low-expectancy experiment, in which response biases should have been absent, inhibition emerged. In essence, Hamburger and Slowiaczek claimed that response biases worked in opposition to inhibit lexical processes, masking their emergence, an effect that appeared only when biases had been effectively neutralized by decreasing PRP and ISI.

Although the account offered by Hamburger and Slowiaczek (1996) is reasonable, it hinges on the assumption that reducing the PRP and ISI was sufficient to eliminate response biases. Goldinger (1999) expressed doubts about this assumption. In a replication of Hamburger and Slowiaczek (1996), he argued that biases were not removed in the low-expectancy experiment, because responses to 0-overlap trials slowed over the course of the experiment, a reliable indicator that response strategies were at work (Posner & Snyder, 1975; see also Goldinger et al., 1992, Experiments 1 and 2). Hamburger and Slowiaczek (1999) countered that biases were sufficiently minimized in Hamburger and Slowiaczek (1996) to consider the 3-overlap data an accurate reflection of lexical processes.

There seems to be a consensus among researchers that response bias causes the RT facilitation in the 1- and 2-overlap conditions (Radeau et al., 1995), but the cause of the slowdown in the 3-overlap condition is still in dispute: Is it due to response bias or lexical inhibition? The purpose of the present study was to help resolve this dispute. Our approach combined a few of the methods of Goldinger (1998). Whereas Goldinger focused only on the RT costs (i.e., slowdown) in the 0-overlap trials over the course of the experiment as a measure of response biases, we also measured corresponding changes in the 3-overlap condition. In addition, we slightly altered the design of a standard phonological priming experiment to probe lexical processing at multiple points during the testing session. First, similar to Goldinger (1998; see also Goldinger, 1999), the experiment was split into two blocks. The first consisted of 35 0-overlap (i.e., unrelated) prime–target trials. Its purpose was to establish an attentional set in listeners free from expectations of overlap. RTs to 0- and 3-overlap trials could then be measured in this state in the beginning of the second block.

The second block consisted of randomly ordered trials of varying overlap (0–3 phonemes) between prime and target, equivalent to what is found in a typical phonological priming experiment. To detect the presence of response biases, we measured responses to a subset of target words at the beginning and end of this block. At each of these probe positions, the subset of targets occurred on two consecutive trials, the first preceded by a 0-overlap prime and the second preceded by a 3-overlap prime. Targets were rotated through these probe positions across stimulus lists, making it possible to compare responses to the same items in different positions in the block and when preceded by 0- and 3-overlap primes. The sequencing of trials is depicted in Table 1.

If the response slowdown in the 3-overlap condition reflects mostly lexical inhibition, then slowdowns of a similar magnitude should be found in both the early and late probe positions. Differences across probe positions would suggest that naming times reflect the operation of other processes as well, a likely candidate being response biases, given their presence in past studies. In any experimental setting, participants have to adopt a strategy to perform the task required of them. The probe-position methodology is one way to measure whether the strategy remains fixed and how the strategy affects responding.

Across four experiments, we ran this probe-position paradigm through manipulations used in past phonological priming studies (e.g., varying PRP and ISI). As will be seen, we found large effects of bias, and manipulations of PRP and ISI were ineffective in ameliorating their impact. An alternative explanation of the pattern of RT results across overlap conditions is proposed.

Table 1
Sequencing of Trials in the Experiments, With Example Stimuli

Trial no.	Prime–target	No. of overlapping phonemes
	0-overlap trials (Expts. 1–4: Trials 1–35)	
1	head–chance	0
2	mull–friend	0
35	fry–quill	0
	Early probe position (Expts. 1–4: Trials 36 and 37)	
36	brace–plan	0
37	glad–glass	3
	Varying-overlap session (Expt. 1: Trials 38–89; Expts. 2 and 3: Trials 38–198)	
38	joy–joint	2
39	gave–grips	1
40	black–blast	3
41	sash–belch	0
	Late probe position (Expt. 1: Trials 90 and 91; Expts. 2 and 3: Trials 199 and 200)	
Next to last	wish–farm	0
Last	snap–snack	3

Note. In Experiments 2 and 3, a mid probe position occurred in the varying-overlap session, somewhere after Trial 73. A rest break was also included in these experiments, after Trial 91. Expt. = Experiment.

Experiment 1

The aim of Experiment 1 was to test the probe-position paradigm in an experimental setup in which bias effects have been found. The experiment was a replication of Hamburger and Slowiaczek (1996, Experiment 1) except for the procedural changes described above. The ISI was 500 ms, the PRP was similar, and we even used a subset of their stimuli. If response biases are to be found in the 3-overlap condition, then they should appear under these circumstances. If they do not, then the paradigm is probably insensitive to what it was intended to measure.

Method

Participants. A total of 192 Ohio State University students participated in exchange for course credit. All were native speakers of English and reported no speech or hearing difficulties.

Stimuli. M. Hamburger provided the stimuli used in Hamburger and Slowiaczek (1996). Ninety-one monosyllabic targets (e.g., *state*) were used, each of which had four corresponding monosyllabic primes that differed in the number of overlapping phonemes (0–3) from word onset (e.g., *drive, swim, star,* and *steak*).

One of us (L.S.) recorded these words onto digital audio tape at 48 kHz. They were then digitally transferred to the hard disk of a PC (downsampled to 16 kHz; low-pass filtered at 7.6 kHz), where they were edited and saved as individual sound files. The targets averaged 596 ms in duration. The average prime duration across the four overlap conditions varied by 50 ms (0 overlap = 594 ms; 1 overlap = 620 ms; 2 overlap = 637 ms; 3 overlap = 645 ms).

Design. We believe it is easiest to think of this experiment as having two designs. One design resembled Hamburger and Slowiaczek (1996), in which a set of targets was paired with each of its primes (0–3 overlap) across stimulus lists such that responses to the same targets could be compared across the four overlap conditions. Because prime and target overlapped by 0–3 phonemes, we refer to this part of the experiment as the *varying-overlap session,* as depicted in Table 1.

A separate set of prime–target word pairs was used to measure priming at the beginning and at the end of the varying-overlap session. As shown in Table 1, two probe positions (early and late) were crossed with two overlap conditions (0 and 3 phonemes).

The experiment began with 35 0-overlap trials, in which the prime–target pairing remained fixed for all participants. Trials 36 and 37 defined the early probe position, and Trials 90 and 91 defined the late probe position. The first trial of each pair (36 and 90) was a 0-overlap trial, and the second trial of each pair (37 and 91) was a 3-overlap trial. Trial 37 was therefore the first phonemically overlapping trial of the experiment, and Trial 91 was the last overlapping trial. Twenty-four target words appeared in each of these probe positions by rotating them through the four trials across stimulus lists. Because only four of these targets were presented to any 1 participant, 24 stimulus lists had to be created to rotate all targets through all four Overlap × Probe Position conditions (i.e., Trials 36, 37, 90, and 91).

The remaining 52 targets were presented in the varying-overlap session (Trials 38–89), with an equal number (13) of 0-, 1-, 2-, and 3-overlap trials occurring in a randomly permuted order. Each target was paired with each of its four primes across stimulus lists such that these varying-overlap targets occurred in all four overlap conditions.

Of the 91 trials in each list, 41 prime–target pairs overlapped by 1–3 phonemes, yielding a PRP of 45% for the experiment. Not including the 35 0-overlap trials, primes overlapped with targets on 80% of the trials.

Procedure. Participants were tested up to 2 at a time in individual sound-attenuated booths. Stimulus presentation and response collection were controlled by a PC. Participants listened to the word pairs through headphones at a comfortable listening level and responded by naming the target into a microphone placed approximately 4–6 in. (10.2–15.2 cm) in front of their mouths. In each trial, a prime was presented, followed by a 500-ms ISI and then a target. Participants were instructed to listen to the pair of words and to repeat the second word into the microphone as quickly as possible. Fast naming was emphasized. No mention was made of the phonological overlap between prime and target. Naming times from the onset of the target were collected through the activation of a voice key, which stopped a computer-controlled clock. Participants had 3.5 s from target offset to respond before the next trial began. Responses were tape recorded and checked for accuracy at a later time. Twenty practice trials, in which only 0-overlap prime–target pairs were presented, preceded the 91 test trials. There were 8 participants tested on each of the 24 lists.

Results

Shadowing times less than 100 ms (1.8%) were excluded from the analysis. Errors did not exceed 3% in any of the overlap or probe conditions, and no analyses performed on them were reliable. Therefore, we do not discuss them further.

Shown in the top left graph of Figure 1 are the mean shadowing times to targets presented during the varying-overlap session when targets were preceded by the four types of primes. Despite the fact that RTs were about 200 ms shorter than those in Hamburger and Slowiaczek (1996), the pattern of RTs resembles theirs. RTs in the 1- and 2-overlap conditions were shorter than those in the 0-overlap condition (13 ms and 15 ms, respectively), replicating the facilitatory effect that is an index of response biases. RTs in the 3-overlap condition were 17 ms longer than those in the 0-overlap condition. A one-way analysis of variance (ANOVA) performed on the data in these conditions was reliable by subjects and items,

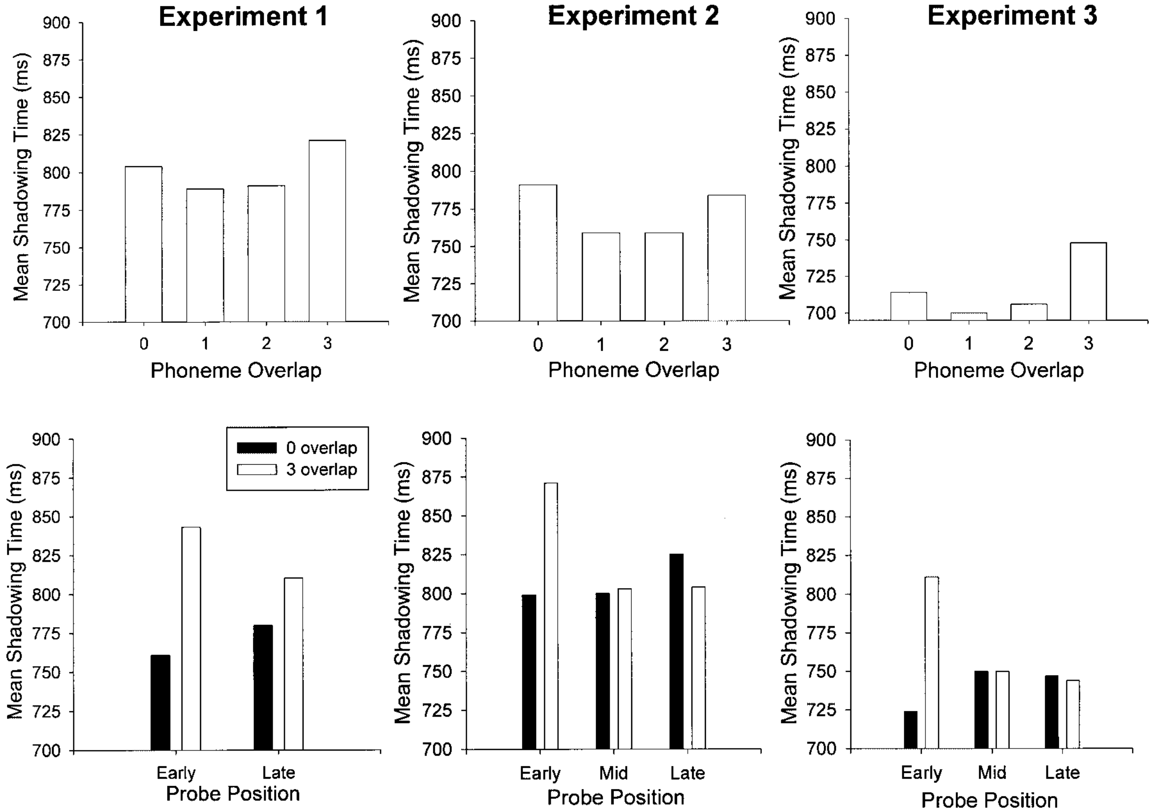

Figure 1. Data from Experiments 1–3 (first, second, and third columns, respectively). Top row: Mean shadowing times as a function of overlap condition. Bottom row: Mean shadowing times as a function of probe position and overlap.

$F_1(3, 573) = 47.46$, $p < .001$, and $F_2(3, 153) = 14.40$, $p < .001$. Comparisons between conditions showed that responses in the 1- and 2-overlap conditions were reliably faster than those in the 0-overlap and 3-overlap conditions. No other comparisons reached significance.

The purpose of Experiment 1 was to find direct evidence of response biases in 3-overlap trials using a modified experimental design. Inspection of the mean shadowing latencies across the two probe positions (bottom left graph of Figure 1) suggests such biases were present. Because a subset of targets appeared in all four conditions, naming differences should have been due to only the amount of overlap if response biases were absent. As can be seen, shadowing times also differed substantially across probe positions. RTs in the 3-overlap condition decreased, and those in the 0-overlap condition increased, causing the size of the response slowdown to decrease from the early to the late probe position. In the early position, shadowing times in the 3-overlap condition were 82 ms longer than those in the 0-overlap condition, $F_1(1, 184) = 36.70$, $p < .001$, and $F_2(1, 23) = 18.96$, $p < .001$.[1] In the late probe position, this difference shrank to a nonsignificant 30 ms, $F_1(1, 183) = 1.54$, $p < .22$, and $F_2 < 1$. A two-way interaction between overlap and probe position was reliable by subjects and approached significance by items, $F_1(1, 176) = 11.32$, $p < .001$, and $F_2(1, 23) = 2.69$, $p < .12$. The changes in shadowing times across probe position in each overlap condition were reliable by subjects but not by items: 3-overlap condition, $F_1(1, 187) = 4.09$, $p < .05$, and $F_2(1, 23) = 1.52$, $p < .23$; 0-overlap condition, $F_1(1, 180) = 6.75$, $p < .01$, and $F_2(1, 23) = 1.23$, $p < .28$.

Discussion

The varying-overlap results replicate quite closely those of Hamburger and Slowiaczek (1996). Across the overlap conditions, there was reliable RT facilitation in the 1- and 2-overlap conditions, and weak (but nonsignificant) inhibition in the 3-overlap condition. Even this small slowdown in naming in the 3-overlap condition (17 ms), which differs from the 0-ms effect of Hamburger and Slowiaczek, was not unexpected. These authors obtained a comparable slowdown (16 ms) in a very similar experiment (Slowiaczek & Hamburger, 1992, Experiment 2a).

Comparison of responses to the same targets across probe positions revealed what was expected, given the long ISI and a high PRP of the experiment: Response biases emerged in the 3-overlap condition. Thus, the slowdown in shadowing may not be caused

[1] Degrees of freedom for the probe-position subject analyses are sometimes smaller than one might expect. Because each participant contributed only one observation to each probe-position condition, when an error was made on any one of these trials (which was rare), there was one less observation to contribute to the analysis, thus reducing degrees of freedom.

solely by lexical inhibition, in which prior activation of lexical candidates by the prime slows processing of the target.

The findings of Experiment 1 in some ways raise more questions than provide answers. Although the results demonstrate that the probe-position paradigm is sensitive to response biases and that these biases are present in the 3-overlap condition, we want to know whether a similar pattern would be found in a low-expectancy setup, with a short ISI and a low PRP. In addition, a surprising outcome was the large response slowdown in the early probe position. What was its cause? Finally, despite being statistically nonsignificant, is the 30-ms slowdown in the late probe position evidence of pure lexical inhibition, with any bias effects having dissipated by the end of the testing session? After all, the size of this effect is comparable with that found in past studies. Experiments 2–4 addressed these questions.

Experiment 2

If the RT difference in the late probe position reflects lexical inhibition, then by doubling or tripling the number of trials in the varying-overlap session and measuring priming at the end of this lengthened experiment, the slowdown should also be about 30 ms. Such an outcome would be good evidence of lexical inhibition in the absence of response biases. On the other hand, this response slowdown might be a snapshot of an evolving response bias. By lengthening the experiment, performance in the 0- and 3-overlap conditions might continue to converge, wiping out the slowdown.

Experiment 2 tested these alternative explanations. The experiment was similar to Experiment 1 except for a few modifications. First, the length of the varying-overlap session was increased threefold. By moving the late probe position to much later in the experiment, the two hypotheses described above were tested. A second change, intended to provide information on the evolution of a response strategy, was that the prime–target pairs occurring in the early and late probe positions were also included in the varying-overlap session (referred to as the mid probe position), such that there were, in essence, three probe positions instead of two. We also attempted to improve the economy of the experiment by testing fewer participants and using fewer targets across probe positions.

Method

Participants. A total of 96 undergraduates from the same population as Experiment 1 participated. None participated in Experiment 1.

Stimuli. Twelve of the 24 prime–target pairs that were used in the probe conditions of Experiment 1 were reused in those same conditions in Experiment 2. The other 12 pairs served as varying-overlap trials. The first 35 0-overlap trials that began the test session were also the same as in Experiment 1.

Additional varying-overlap trials had to be included to extend the length of the testing session. The limited availability of targets that had 1-, 2-, and 3-overlap primes (we had exhausted the pool) restricted the number of varying-overlap trials to 161 (52 of which occurred in Experiment 1) and also required a few other modifications. Five of these were warm-up trials, which followed a rest break; they were not included in the data analysis. An additional 28 trials were permanent trials, in that the prime–target pairing remained fixed across stimulus lists. Six were 0-overlap trials, eight were 1-overlap trials, eight were 2-overlap trials, and six were 3-overlap trials. Responses to the targets of these permanent trials were also not analyzed. The additional stimuli were recorded by one of us (L.S.).

This left 128 targets for which there were primes that had 0–3 overlapping phonemes. In each stimulus list, eight of these word pairs were actually the remaining eight (from the total of 12) that did not occur in the early and late probe positions. For example, if *must* appeared as a target in each of the four probe positions across Lists 1–4, it appeared as a varying-overlap trial in Lists 5–12. It was a 0-overlap target in Lists 5 and 6, a 1-overlap target in Lists 7 and 8, a 2-overlap target in Lists 9 and 10, and a 3-overlap target in Lists 11 and 12. The probe condition targets were reused in this manner to create a third, mid probe position to measure responses to the same items in the middle of the testing session. In addition, it was necessary to reuse these targets, rather than keep them separate from the varying-overlap targets as in Experiment 1, to lengthen the varying-overlap session as much as possible.

As in Experiment 1, the 12 probe-position targets were paired with 0- and 3-overlap primes in the three probe positions (early, mid, and late) across stimulus lists. There were 12 lists in all.

With a total of 161 varying-overlap trials, the late probe positions were now Trials 199 and 200. The early probe positions were again Trials 36 and 37. The mid probe positions were not fixed, but occurred in different points in the varying-overlap session (always after Trial 73) depending on the stimulus list. A rest break was placed immediately after Trial 91 such that the data from the first half of the experiment could be compared with those of Experiment 1, in which there were 91 trials. In total, there were 200 trials in each stimulus list: 35 0-overlap trials, which began the experiment; 2 early probe position trials; 54 varying-overlap trials; the rest break; 102 varying-overlap trials, the first 5 of which were a warm-up; and 2 late probe position trials. Two mid probe position trials occurred during the varying-overlap session. The prime and target overlapped by at least one phoneme in 122 trials (resulting in an overall PRP of 45%). From onset of the early probe position onward, such overlap occurred on 74% of trials.

Procedure. The procedure was the same as that of Experiment 1.

Results

Shadowing latencies less than 100 ms (accounting for less than 1% of the data) were excluded from the analysis. Errors did not exceed 2% in any one condition, and we do not discuss them further.

Mean shadowing times in the four overlap conditions are shown in the top middle graph of Figure 1. The data closely resemble those of Experiment 1. RTs in the 1- and 2-overlap conditions were 32 ms shorter than those in the 0-overlap condition. The 3-overlap condition also showed a very slight speedup as well (7 ms). A one-way ANOVA across these four conditions was reliable, $F_1(3, 288) = 17.01$, $p < .0001$, and $F_2(3, 357) = 6.32$, $p < .001$. Individual comparisons between conditions showed that the 0- and 3-overlap conditions did not differ reliably from each other. Neither did the 1- and 2-overlap conditions, but both of these were reliably faster than the 0- and 3-overlap conditions.

The probe-position data (bottom middle graph of Figure 1), replicate and extend the results of Experiment 1. There was a large (70-ms) slowdown to 3-overlap targets in the early probe position, which is comparable with that found in Experiment 1 (82 ms). In the mid probe position, this slowdown disappeared (3 ms). By the late probe position at the end of the lengthened experimental session, there was a surprising reversal, with 3-overlap RTs being 21 ms shorter than 0-overlap RTs. This difference, however, was not reliable, as statistical comparisons between the overlap conditions in each probe position reached significance only in the early probe position, $F_1(1, 94) = 19.85$, $p < .0001$, and $F_2(1, 11) = 5.62$, $p < .04$. A 2 × 3 ANOVA performed across the six conditions yielded a reliable interaction of Overlap × Probe Position in the subjects analysis, $F_1(2, 187) = 8.47$, $p < .001$. In the items analysis, the interaction approached reliability, $F_2(2, 22) = 2.54$, $p < .10$. Low power probably prevented this interaction from reaching statistical significance.

As in Experiment 1, the convergence of the 0- and 3-overlap RTs across probe position was due to 3-overlap responses speeding up and 0-overlap responses slowing down. These opposite effects were asymmetrical, with the drop in RT in the 3-overlap condition (67 ms) being more than twice as great as the increase in RT in the 0-overlap condition (26 ms). One-way ANOVAs showed these changes across probe position to be reliable for only the 3-overlap case, $F_1(2, 188) = 8.32$, $p < .003$, and $F_2(2, 22) = 3.69$, $p < .01$.

Discussion

The aim of Experiment 2 was to determine whether the response slowdown in the late probe position in Experiment 1 would level off and remain constant when the test session was lengthened. Such a lingering effect would suggest that the slowdown was due to lexical inhibition. Instead, the response slowdown was not merely eliminated but reversed itself, with RTs in the 3-overlap condition shorter than those in the 0-overlap condition (although not statistically reliable).

These findings suggest that powerful response biases affected responding in the 3-overlap condition. The slowdown in the 0-overlap condition is also suggestive of this. The magnitude of these changes and their evolution over trials suggests that participants apply a response strategy that maximizes fast naming in the experiment. The type of bias we have in mind here is a response strategy that is initiated once phoneme overlap between prime and target is noticed.

Given that participants are charged with responding as quickly as possible in the experiment, it makes sense for them to use any information available to achieve this goal. Phoneme overlap between prime and target is an obvious source. One reason such a strategy might be successful is that both prime and target are presented auditorily, which takes time (i.e., 550 ms or more for each word). This is perhaps enough time for participants to listen to the initial phoneme or phonemes of the prime and anticipate their repetition when the target is presented, thus facilitating shadowing. The 500-ms ISI between prime and target would certainly aid participants in this regard. Furthermore, when overlap occurs on such a high proportion of trials (74%), there is ample opportunity to practice such a strategy and improve it over the course of the experiment. Such a strategy might be successful on 1- and 2-overlap trials as well.

Deployment of such a response strategy may be minimally affected by experimental manipulations that are thought to minimize response biases, particularly PRP. If participants need only notice the overlap between prime and target on a single trial (possibly the first one of the experiment) before beginning to implement such a strategy, it is difficult to imagine how reducing the number of overlap trials would prevent the strategy from being adopted. The most this reduction in trials would do is decrease the salience of the overlap such that the overlap might not be noticed as early in the testing session. Although shortening ISIs gives participants less time to apply a strategy on each trial, there might still be enough time to do so. Because both stimuli are presented auditorily, there is at least 1 s from prime onset to target offset. This might be sufficient time for participants to ready a pronunciation of only the first one or two phonemes of the prime. If the assembled pronunciation is correct, shadowing times should be facilitated. If these observations are correct, strategic effects may be insidious in phonological priming experiments.

We investigated the preceding ideas in Experiment 3, which was a replication of Experiment 2 but with a 50-ms ISI and a 10% PRP, a direct test of whether response biases would appear in the 3-overlap condition in a low-expectancy experiment. The probe-position analysis would resemble that found in the two preceding experiments if such modifications are minimally effective in thwarting the type of response strategy we have in mind.

Experiment 3

Method

Participants. A total of 84 undergraduates from an introductory psychology course participated in exchange for course credit, 7 participants for each of the 12 stimulus lists.

Stimuli. The experiment was the same as in Experiment 2, except that the primes and targets in 113 of the 128 varying-overlap trials were re-paired with one another such that the proportion of trials in which the prime and target overlapped by one or more phonemes was reduced to 8.5% across all 200 trials (15 in the varying-overlap trials and 1 in the early, mid, and late probe positions). When measured from the early probe position, the PRP was 10%.

Twenty targets (five of each degree of overlap) were rotated through the four overlap conditions across four stimulus lists (i.e., Lists 1–4). This process was repeated twice with a different set of 20 targets each time for the remaining two sets of four lists (i.e., Lists 5–8 and Lists 9–12) to yield 60 targets that occurred in all four overlap conditions.

Procedure. The procedure was the same as that in Experiment 2.

Results

Shadowing times less than 100 ms were removed from the analysis (accounting for less than 2% of the data). Errors were again negligible across conditions (less than 3%), and we did not analyze them further.

Mean shadowing latencies across the overlap conditions are shown in the top right graph of Figure 1. RTs in the 1- and 2-overlap conditions showed a slight decrease relative to the 0-overlap condition (14 ms and 8 ms, respectively). In contrast, the response slowdown in the 3-overlap condition was sizeable (34 ms). A one-way ANOVA was reliable by subjects and items, $F_1(3, 249) = 15.55$, $p < .0001$, and $F_2(3, 157) = 4.27$, $p < .006$. This pattern of data replicates that of Hamburger and Slowiaczek (1996, Experiment 2), in which response biases were assumed to be absent because a large slowdown of responses emerged in the 3-overlap case under experimental conditions thought to prevent biases (low PRP and short ISI).

The probe-position data (bottom right graph of Figure 1) suggest that biases were present, however, in that the data closely resemble those in the adjacent graph (bottom middle), with a large slowdown to the first 3-overlap trial that is eliminated by the last trial of the experiment. In the early probe position, the 85-ms slowdown was reliable, $F_1(1, 81) = 24.77$, $p < .001$, and $F_2(1, 11) = 5.89$, $p < .03$. The 0- and 3-overlap means were identical in the mid probe position, and there was a 3-ms reversal in the late position

(Fs $<$ 1). The Overlap × Probe Position interaction was reliable by subjects, $F_1(2, 156) = 7.76$, $p < .001$, and marginal by items, $F_2(2, 22) = 2.96$, $p < .07$. The amount by which RTs changed over probe positions was also comparable with that in Experiment 2. There was a 65-ms drop from the early to late probe positions for the 3-overlap trials, $F_1(2, 159) = 7.47$, $p < .001$, and $F_2(2, 22) = 2.80$, $p < .08$, and a 23-ms increase in 0-overlap trials (Fs $<$ 1).

Discussion

The results of Experiment 3 demonstrate that shortening the ISI and reducing the PRP did not alter participants' response behavior across the course of the experiment. A large slowdown in the early probe position disappeared by the late probe position. The magnitudes of RT changes across probe positions were even similar across Experiments 2 and 3, with large drops (67 ms and 85 ms, respectively) in RTs in the 3-overlap condition and modest rises (26 ms and 23 ms, respectively) in RTs in the 0-overlap condition.

That the data in the early probe position in Experiments 2 and 3 are comparable is not unexpected, as the experiments were identical to each other up to this point in the testing session, except for the difference in ISI. Only afterward did they differ in the proportion of overlapping trials. Perhaps not surprising, then, is that it is in the late probe position where small differences were found. In Experiment 2, 3-overlap RTs were 21 ms shorter than those in the 0-overlap condition, but they were only 3 ms shorter in Experiment 3. Although neither difference was reliable, the failure to find a larger effect in Experiment 3 may be due to participants having had far fewer overlap trials on which to practice implementing an overlap-guided response strategy (16 in Experiment 3 vs. 98 in Experiment 2) and also may be due to these overlap trials being less predictable. This possibility is explored more fully in the General Discussion.

Experiment 4

Experiment 4 was a final attempt to measure lexical inhibition using phonological priming. The results of Experiments 1–3 indicate response strategies develop very early in the experiment, possibly after the first overlap trial. Because of this, the early probe position may be the only point in the experiment at which lexical processing effects, uncontaminated by participants' expectations of phoneme overlap, might be observed. Such effects should be evident in the data of those participants who did not notice the overlap between prime and target on this trial.

Experiment 4 was a replication of Experiment 3, but testing stopped immediately after the early probe position (Trial 37). Participants then answered a series of questions about the relationship between the prime and target on Trial 37 so that we could determine whether they noticed the overlap. By analyzing RTs as a function of their answers, we would be able to dissociate effects due solely to lexical processing from those due to lexical processing and noticing the phoneme overlap (see Stark & McClelland, 2000, a recent article that used a similar analysis procedure). If participants are surprised, almost startled, by the sudden presence of the overlap, the slowdown in responding might be due to surprise rather than lexical inhibition.

Method

Participants. A total of 96 undergraduates participated.

Design. The design of the experiment was the same as that in Experiment 3, except that testing stopped immediately after the early probe position. 0-overlap word pairs were presented on Trials 1–36, and a 3-overlap pair was presented on Trial 37. The ISI was 50 ms.

Stimuli. The 24 targets from Experiment 1 along with their 3-overlap primes were used. As before, targets were rotated through the two trials in the early probe position across lists. Four participants were tested in each of the 24 lists.

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

Results and Discussion

Mean RTs in the 0- and 3-overlap conditions were 726 ms and 800 ms, respectively. The slowdown on the lone 3-overlap trial was similar in magnitude to that in the preceding experiments (74 ms), $t_1(95) = 4.06$, $p < .0001$, and $t_2(23) = 1.83$, $p < .08$. Participants' data were classified according to whether they noticed the phoneme overlap on the last trial, on the basis of answers to a series of questions on a postexperiment survey. Those who answered a subset of multiple-choice questions correctly (e.g., word-initial overlap and overlap occurred only on the last trial) were classified as having noticed the overlap. A total of 84% met this criterion, and these participants yielded a response slowdown of 66 ms. The 15 participants who did not notice the overlap yielded a whopping 132-ms slowdown. This huge effect is not representative of all participants in this group, as there were three outlying scores that were the three largest slowdowns in the experiment (greater than 550 ms). Removal of these RTs reduced the mean to 13 ms. With so few participants in this latter group, strong conclusions about the lack of a slowdown are probably unwise. Nevertheless, precisely because responses slowed for most participants who noticed the overlap, surprise seems a reasonable cause of the slowdown.

The salience of a 3-phoneme overlap trial indicates that it will be difficult to separate true lexical effects from strategic or surprise effects in phonological priming studies that include high-overlap prime–target pairs. The overlap is so salient that most participants noticed it when the first 3-overlap word pair was presented. As the results of Experiments 1–3 suggest, participants then implement a strategy that capitalizes on its presence. The best course of action that one could take would be to incorporate into the experimental design manipulations that counteract such strategies. Goldinger (1998, 1999) suggests a few possibilities.

General Discussion

Researchers using phonological priming have been just as preoccupied with eliminating and examining bias effects as investigating lexical processes. This is as it should be with a paradigm that has the potential to shed as much light on lexical memory as phonological priming. The present study sought to clarify whether the response slowdown in the 3-overlap condition reflects lexical inhibition (Hamburger & Slowiaczek, 1999) or a response bias (Goldinger, 1999) by slightly varying the standard experimental setup.

By measuring responses to the same targets at various points during the experiment, we found clear evidence of response biases.

The data across Experiments 1–3 are impressively consistent in demonstrating that the response slowdown on 3-overlap trials is not constant over the course of the experiment, as one would expect if lexical processes were primarily responsible for the effect. Instead, there was a trade-off across overlap conditions, with 0-overlap RTs increasing slightly across probe positions and 3-overlap RTs decreasing dramatically. This latter change was so great that a large, probably surprise-induced slowdown in the early probe position vanished by the middle of the experiment (Experiments 2 and 3) and even reversed itself in the late probe position. These systematic changes in responding over the experiment remained hidden when data were averaged over trials because, as the probe-position graphs in Figure 1 show, costs in responding at one end of the experiment were offset by benefits at the other end.

That response biases were found in Experiments 1 and 2 might not be too surprising, given that the experimental setup was thought to induce it: PRP was set high and ISI was set long. That biases of comparable magnitude were found when the values of both variables were significantly reduced (Experiment 3) provides the strongest evidence that response biases can severely distort results in the 3-overlap condition. The data in Figure 1 show that responses were not just mildly distorted.

The results of these four experiments suggest that participants are initially surprised upon encountering a 3-overlap trial, which causes the slowdown in the early probe position. Noticing the overlap triggers the development of a response strategy that capitalizes on the overlap between prime and target. The strategy is honed as it is practiced, which is why RTs in the 3-overlap condition decreased over the testing session. The reason the strategy succeeds even when PRP and ISI are reduced is that neither prevents its implementation. The overlap is so salient that it took only a single trial for most participants to notice it. A lower PRP provides fewer opportunities to apply the strategy but does not prevent its adoption once the overlap is noticed. Although a shorter ISI provides less time to respond, it makes little difference when the prime and target together require over 1 s to present. More drastic measures might be required to prevent successful application of such a strategy, such as using compressed speech or presenting the prime and target to opposite ears.

A Single Response Bias?

Identification of a response bias in the 3-overlap condition raises the question of whether it is the same type of bias at work in the 1- and 2-overlap conditions. Any such account that is put forward has to explain why, in the overall analyses (top graphs in Figure 1), the 3-overlap condition consistently yielded an outcome that was qualitatively different from that in the 1- and 2-overlap conditions.

As reviewed in the introduction, Hamburger and Slowiaczek (1996) have appealed to a combination of lexical processing and bias to explain this finding. Because the RT facilitation disappeared in the 1- and 2-overlap conditions when expectancies of overlap were low (i.e., with a low PRP and a short ISI), such effects were thought to be due to response bias. The response slowdown in the 3-overlap condition was argued to be due to lexical inhibition precisely because the slowdown was found when expectancies were low. In light of the results of our Experiment 3, in which a similar manipulation of expectancies minimally affected the probe-position results, a lexical inhibition account seems doubtful.

In its place, we propose that the differences found as a function of expectancy (low vs. high) are due to practice effects from honing a response strategy that is induced by noticing the overlap. One by-product of manipulating PRP is that participants have more trials in which to apply a response strategy, such as anticipating that the target will start with the same sound sequence as the prime, when PRP is high. With additional practice, participants are likely to improve performance in the 1- to 3-overlap trials and to respond faster.

This is just what we found when we compared the low- and high-expectancy data. Shown in Figure 2 are the mean RT difference scores (e.g., 0-overlap condition minus 3-overlap condition) across conditions in the low- and high-expectancy experiments of Hamburger and Slowiaczek (1996; top graph) and Goldinger (1999; second graph). The third graph displays comparable data from Experiments 2 (high expectancy) and 3 (low expectancy) of the present study. Positive values indicate responses were faster than those in the 0-overlap condition; negative values indicate responses were slower than those in the 0-overlap condition. Note that all three of these graphs show that responses in the three overlap conditions sped up, shifting upward from the low-expectancy experiments (black bars) to the high-expectancy experiments (white bars). RTs in the 1- and 2-overlap conditions became more positive, and the RTs in the 3-overlap conditions became less negative. In the high-expectancy experiments, participants responded faster because they had more practice with overlap trials.

More direct evidence that RT differences as a function of expectancy are due to practice is shown in the bottom graph of Figure 2, in which mean RT difference scores were calculated for the trials before and after the rest break in Experiment 2 of the present study. After the rest break, participants had more practice. This is evident in the data but not as one might expect. RTs did not simply drop uniformly across all four overlap conditions (0–3) after the break. Rather, responses in the 1- to 3-overlap conditions sped up much more than those in the 0-overlap condition. The net effect was that after the break, RTs in the 1- to 3-overlap conditions shifted upward as a group and were shorter than those before the break, $F_1(2, 95) = 26.05$, $p < .001$. This pattern of data is strikingly similar to that in the top three graphs, demonstrating that practice is responsible for the changes across expectancy manipulations. Said another way, a response slowdown in the 3-overlap condition is only a slowdown when there are few trials in which prime and target share phonemes.

Although a practice-based account may explain why RTs in the 1- to 3-overlap conditions shift relative to the 0-overlap condition, it does not explain why responses to 3-overlap targets are always slower than responses to 1- and 2-overlap targets. At present, we can only speculate about the cause. The data of Experiment 4 support the idea that the slowdown is due initially to a surprise response. However, a surprise effect should not linger over so much of the testing session. Properties of the stimuli themselves may hold the key to explaining this anomaly. In Experiment 1, 63% of the varying-overlap targets had a consonant-consonant-vowel-consonant (CCVC) word structure (e.g., *snack*), with the remainder being consonant-vowel-consonant-consonant (CVCC) words (e.g., *dense*). When we partitioned the item data by the word

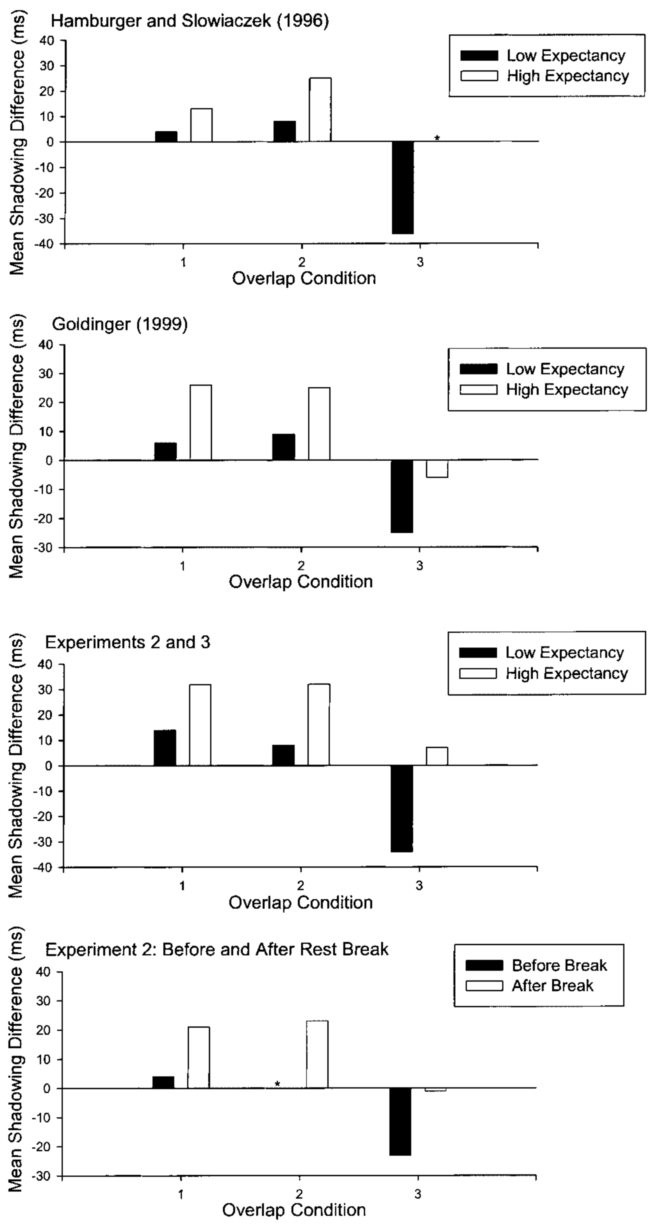

Figure 2. Differences in shadowing times (0-overlap condition minus the 1-, 2-, or 3-overlap conditions) in the low-expectancy (low PRP and short ISI) and high-expectancy (high PRP and long ISI) experiments from Hamburger and Slowiaczek (1996; top graph), Goldinger (1999; second graph from top), and this study (second graph from bottom and bottom graph). In the bottom graph, the same analysis was performed on the data of Experiment 2, as a function of whether responses were before or after the break. Asterisks denote conditions in which the difference score was zero.

structure of the target, we found that the response slowdown in the 3-overlap condition was more than three times greater for CVCC words (M = 48 ms), $t(13) = 4.61$, $p < .01$, than for CCVC words (M = 13 ms), $t(37) = 1.49$, $p < .14$. The substantially larger slowdown for the CVCC words was impressively consistent across items, with 12 of the 14 words exhibiting the effect in the same direction (range = 27–94 ms). Word structure had minimal effects on responding in the 1- and 2-overlap conditions.[2] Because the difference in responding to the two word structures was confined to the 3-overlap condition, it suggests that listeners were surprised when the prime and target overlapped by a consonant following a vowel (e.g., *dent–dense*). The low frequency with which these CVCC 3-overlap trials occurred, coupled with the fact that they were sprinkled throughout the testing session, may explain why surprise persisted for so long into the experiment. Listeners not only had to adapt to there being overlap, but expectations about the dominant word structure were violated periodically.

Reanalysis of Hamburger and Slowiaczek (1996)

The results of the present experiments were collected using a variant of the standard phonological priming setup in which the overlapping trials occurred only after a sequence of 35 0-overlap trials. It is reasonable to ask what impact this change in procedure had on participants' performance as well as whether and how these data differ from those collected with the standard setup. The fact that the data patterns across the four overlap conditions in Experiments 1–3 parallel those of past studies (Goldinger, 1999; Hamburger & Slowiaczek, 1996; Slowiaczek & Hamburger, 1992) suggests this slight change in procedure had minimal impact on the outcome. Nevertheless, the claims we have made regarding strategic effects in the present investigation would be strengthened by finding evidence of these same influences in the data of these past studies. M. Hamburger kindly provided us with the data from the two experiments of Hamburger and Slowiaczek (1996) to make such a comparison.

In our analysis, we looked for evidence of the large response slowdown when the first overlap trial was a 3-overlap word pair. The 10 practice trials in Hamburger and Slowiaczek's (1996) experiments contained no word pairs in which phonemes overlapped; therefore the first overlap trial occurred sometime during the first part of the test session. We performed the analysis on the data of Experiment 2, in which the PRP was low and the ISI was short, so that the first overlap trial would occur as late into the test session as possible, making the comparison as close as possible to that in the present experiments. Of the 84 participants in their experiment, 21 heard a 3-overlap pair as the first overlap trial. This trial occurred over a wide range of trials (Trials 3–27). As in the probe-position analyses, we compared the mean RT on this trial with that on the immediately preceding 0-overlap trial. The resulting data are shown in Figure 3. On hearing a 3-overlap trial, participants' responses slowed an average of 76 ms, which is very similar in size to the slowdown in our Experiments 1–4 (M = 78 ms). Because of one large RT reversal of 539 ms, this effect failed to approach statistical significance. Removal of this participant's data made the effect marginally reliable, $t(19) = 1.95$, $p < .07$.

The two bars on the right side of the graph are estimates of RTs in two consecutive 0-overlap trials at the same trial positions in the

[2] Means in the 0- to 3-overlap conditions, respectively, for each word structure were as follows: CCVC = 801, 789, 785, and 814 ms; CVCC = 748, 744, 746, and 796 ms. We used the data from Experiment 1, because 48 observations contributed to each mean, which were more observations than in any other experiment.

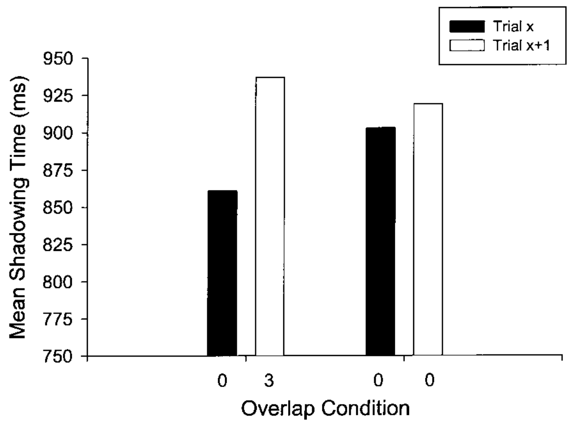

Figure 3. Bars on the left side: Mean shadowing times (for 21 participants) in Hamburger and Slowiaczek (1996, Experiment 2) for the last 0-overlap trial followed by the first 3-overlap trial. Bars on the right side: Comparable data from participants who received two consecutive 0-overlap trials at the same points in the experiment.

testing session as those on the left. (Because these means changed considerably when drawing different samples of RTs, we instead estimated means to provide more representative data. Mean RTs were calculated from 30 randomly selected samples of 21 participants in each trial position.) The difference in RT between the two trial positions shrinks to 16 ms, which suggests that phoneme overlap, and not serial position, is responsible for the large slowdown in responses.

Conclusion

The strong conclusion from the present findings is that the response slowdown in the 3-overlap condition has little to do with lexical processing. The slowdown should be viewed just like the speedups in the 1- and 2-overlap conditions, as it reflects nothing but response bias. From this perspective, the phonological priming paradigm is so fraught with problems of bias that it might be best to abandon it.

Others would argue that such a strong conclusion is premature. The results are informative in alerting researchers to the perils of the paradigm. Although the experiments demonstrate that response biases are present in the 3-overlap condition, they are silent about the existence of inhibitory priming. The fact that inhibition has been found with tasks such as word identification in noise (Goldinger, Luce, & Pisoni, 1989) and word spotting (Norris, McQueen, & Cutler, 1995) makes it reasonable to suppose that inhibitory effects can also be obtained using phonological priming under the right conditions. Indeed, it may well be that participants' response strategies overpower and eventually mask fragile inhibitory effects.

Regardless of which interpretation one favors, we found the probe-position manipulation and accompanying analyses to be useful in identifying effects of response bias.[3] Although the procedure holds promise, it is too early to know the full consequences of the slight changes that we made to the standard phonological priming setup. Nevertheless, the results suggest that the benefits of using the probe-position paradigm outweigh the costs of not doing so.

[3] Graphs from other analyses of the data in the current study, as well as evidence of similar response bias effects in a cross-modal setup, can be retrieved on the World Wide Web from http://lpl.psy.ohio-state.edu, under *Publications*.

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