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The left-to-right nature of the masked onset priming effect in naming

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Two experiments were performed to investigate the nature of the masked onset priming effect in naming, that is, the facilitation in naming latency that is observed when a target shares the initial grapheme/phoneme with a masked prime. Experiment 1 showed that the effect is not due to position-independent letter priming, since the naming of nonword targets preceded by masked primes was facilitated only if the prime shared the initial letter with the target (e.g., *suf*–SIB) and not if the prime shared the final letter (e.g., *mub*–SIB). Experiment 2 showed that the effect reflects the sharing of onsets rather than the initial letter, since facilitation due to an overlap of the initial letter was observed only for the simple onset target (e.g., *penny*–PASTE) for which the letter corresponded to the onset, and not for complex onset targets (e.g., *bingo*–BLISS). It is argued that the serial nature of the masked onset priming effect is best interpreted as the planning of articulation, rather than as the computation of phonology from orthography.

Research on visual word recognition is currently dominated by computational models of reading aloud. The three main implementations are the parallel distributed processing (PDP) model proposed by Plaut, McClelland, Seidenberg, and Patterson (1996); the dual-route cascaded (DRC) model proposed by Coltheart and colleagues (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart & Rastle, 1994); and the parallel dual-route model proposed recently by Zorzi and colleagues (Zorzi, Houghton, & Butterworth, 1998). These models primarily differ in the assumed existence of common or distinct routines for computing phonology for words and nonwords, and in whether the computation of phonology occurs in parallel, or sequentially, across the letter string. All of these models can account for the empirical findings that have become benchmarks for models of word recognition, such as the *word frequency effect* (faster responses to words that occur more frequently in print); the *regularity effect* (words that do not follow the standard spelling-to-sound correspondence rules such as *pint* are named more slowly than words that do, such as *pink*); and the *frequency-by-regularity interaction* (the regularity effect is greater for low-frequency words than for high-frequency words).

Of these models, the DRC model is the only one that incorporates a sequential computational assumption.[1] That is, all other models (Plaut et al., 1996; Zorzi et al., 1998) assume that the derivation of phonology from print occurs in parallel across the letters. Although the DRC model shares this parallel phonemic computation assumption for the lexical route, it assumes a left-to-right serial phonemic computation process across letters on the nonlexical route. This means that the activation coming from the lexical route accrues simultaneously for all phonemes across the string, while the activation coming from the nonlexical route accrues sequentially, from left to right. These two asynchronous sources of input are integrated at the phonemic output buffer, from which an articulatory response is prepared.

Coltheart (e.g., Coltheart & Rastle, 1994; Coltheart, Woollams, Kinoshita, & Perry, 1999) has argued that this sequential phonemic computation assumption gives the DRC model an edge over the other computational models because it provides an explanation for some of the empirical findings that suggest involvement of a sequential process. To date, three such findings have been reported in the literature: the position-of-irregularity effect (Coltheart & Rastle, 1994; Rastle & Coltheart, in press); the length × lexicality interaction effect (Weekes, 1997); and the masked onset priming effect (Forster & Davis, 1991). The *position-of-irregularity effect* refers to the fact that the naming latency disadvantage for an exception word is smaller the later the position of an exception word's irregular grapheme–phoneme correspondence in that word (e.g., *heir* vs. *debris*). The *length × lexicality interaction effect* refers to the finding that the length effect (i.e., the slower naming latency observed with longer letter strings) is more reduced for words than for nonwords. Interpretations of these two effects couched within the DRC model are well articulated in the original sources, and readers are referred to them (Coltheart & Rastle, 1994; Weekes, 1997). The focus of the present study is on the least-studied of the three effects, the masked onset priming effect.

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The masked onset priming effect was first reported by Forster and Davis (1991). The masked priming procedure involves a brief presentation of a prime (typically 50–60 msec) that is then backward masked by the target itself. Because the prime is presented briefly and backward masked, any effect on the target is unlikely to reflect conscious expectancy. Forster and Davis found that in the naming task, response latency to the target was facilitated when the prime shared just the initial letter with the target (e.g., *save*–SINK), relative to a prime that shared no letters with the target (e.g., *farm*–SINK).[2] This masked onset priming effect was not found with high-frequency words or words with irregular spelling-to-sound correspondence (e.g., FETE, AISLE)—that is, items which are assumed to be named via the lexical route. Forster and Davis therefore concluded that the effect reflected the operation of a mechanism specific to the nonlexical route.

The aim of the present research was to investigate the nature of this masked onset priming effect, with a view to substantiating the claim that this provides support for the sequential nature of the nonlexical route. To this end, two questions were examined: first, whether the effect was truly sequential, and second, whether it reflected a characteristic of the computation of phonology from orthography, or of the articulatory process. The first question was examined in Experiment 1, and the second, in Experiment 2.

Surprisingly, to date, there is no direct evidence to indicate that the benefit due to an overlap of just one letter between prime and target is position dependent. Such evidence is crucial to the claim that the masked onset priming effect reflects the operation of a sequential process. The aim of Experiment 1 was therefore to specifically test the position-independent letter priming explanation by comparing the effect of overlap of letters between the prime and target in the left-to-right and right-to-left directions. In order to maximize the possibility that the nonlexical route was used, all stimuli were nonwords. All were three letters long, each with the onset, nucleus, and coda consisting of a single-letter grapheme (e.g., SIB). The targets were preceded by primes that differed from the targets in all three positions: the baseline control condition (e.g., *muf*–SIB); one-letter overlap (e.g., *suf*–SIB or *mub*–SIB); or two-letter overlap (e.g., *sif*–SIB or *mib*–SIB). If the effect reported by Forster and Davis truly reflected a left-to-right sequential process, then facilitation would be expected only if the overlap was from left to right, and not if the overlap was from right to left. That is, facilitation was expected only if the *onset* was shared (e.g., *suf*–SIB) and not if the coda was shared (e.g., *mub*–SIB). Although the masked onset priming effect concerns only the one-letter overlap condition, the two-letter overlap condition was included to see if facilitation was proportional to the amount of overlap.

EXPERIMENT 1

Method

Design. The present experiment constituted a 2 (direction of overlap: left to right or right to left) × 3 (prime–target overlap: one, two, or no letters) factorial design, with both factors manipulated within subjects. The dependent variable was *naming latency*.

Subjects. Eighteen volunteer first-year Macquarie University students participated in the experiment for course credit. All subjects were native Australian-English speakers.

Materials. The critical stimulus materials were 108 three-letter CVC nonwords (e.g., SIB) used as targets in a naming task. They were constructed as 18 sets of six-item groups sharing the onset (e.g., SIB, SEN, SUT, SAN, SAB, SOP). Each target from the six-item group was assigned to one of six experimental conditions so that the targets in the six experimental conditions were equated for onsets. Each experimental condition was defined by a factorial combination of two factors: the amount of overlap between the prime and target (one letter, two letters, and all-letter-different control), and the direction of overlap (left to right or right to left). Examples are shown in Table 1; the set of items used are listed in Appendix A. Half of the items of each of the six-item group were assigned as targets in the left-to-right block, and the other half were assigned as targets in the right-to-left block. Within each block, the assignment of a target to the three prime overlap conditions was counterbalanced across subjects in such a way that each target was seen by a subject only once, and across every 3 subjects it was preceded by primes that shared with the target either one letter, two letters, or no letters.

Apparatus and Procedure. The subjects were tested individually, seated approximately 40 cm in front of an NEC Multisync 4FG monitor upon which the stimuli were presented. The subjects were given two blocks of trials, each consisting of 54 trials, 1 in which the overlap between the prime and target was in the left-to-right direction, and the other in which the direction was right to left. The subjects were unaware, however, of the nature of the difference between the two blocks because the primes were masked. Half of the subjects did the left-to-right block first, and the other half did the right-to-left block first.

Within each block, the subjects were told that a list of nonwords would be shown on the computer screen, one nonword at a time, and that each would be preceded by a series of hash signs. No mention was made of the primes. The subjects were instructed to read aloud each nonword presented in uppercase letters as quickly as possible. Following the instructions, the subjects were given six practice trials. The stimuli were presented in a different random order for each subject.

The instructions and stimuli were presented and reaction time data were recorded to the nearest millisecond using the DMASTR display system (Forster & Forster, 1990)[3] running on a Deltacom 486 IBM-compatible computer. The reaction times were recorded using a voice key fitted to each subject and held a constant distance from the mouth throughout the experiment by means of a headset.

The naming latency was measured by a voice key that delivered a pulse denoting the initiation of articulation, which was recorded by the DMASTR software. Naming errors and possible measurement errors due to inappropriate voice key activation were recorded manually by the experimenter.

Each trial started with the presentation of a forward mask consisting of seven hash signs (#######) for 500 msec, followed by a prime presented in lowercase letters for 56 msec (four cycles of the screen refresh rate), which was in turn replaced by a target presented in uppercase letters. The target remained on the screen for a maximum of 2,000 msec, or until the voice key was triggered by the subject's response. Following a blank screen for 300 msec, the next trial started.

Results and Discussion

Any trial on which a subject error or a voice key error occurred was excluded from the latency analysis. One target item (CEF) in the left-to-right block was removed from all analyses because of a high error rate (16%), which was

Table 1
Mean Naming Latencies (RT, in Milliseconds), Standard Deviations (*SD*), and Percent Errors (%E) with Different Masked Primes in Experiment 1

Type of Prime	Example	RT	*SD*	%E
Left-to-right overlap				
One letter	*suf*–SIB	542	38	1.9
Two letters	*sif*–SIB	539	35	3.4
All letters different	*mof*–SIB	554	37	1.5
Right-to-left overlap				
One letter	*mub*–SIB	551	32	2.5
Two letters	*mib*–SIB	548	37	3.4
All letters different	*mof*–SIB	555	34	4.0

Note—The means and standard deviations of the reaction times are based on the item analysis.

mainly due to voice key trigger failures associated with that item.

In order to reduce the effects of outliers in this and subsequent analyses, spuriously long or short reaction times were trimmed to the cutoff value of two standard deviations above or below the mean for each subject. Analyses treating the subjects as a random variable (F_s) and treating the items as a random variable (F_i) will be reported here, and an effect was considered to be significant when both the subjects analysis and the items analysis were significant at the .05 level. The left-to-right block and the right-to-left blocks were analyzed separately in one-way analyses of variance (ANOVAs), with the amount of overlap as a within-subjects factor in the subjects analysis and as a within-items factor in the items analysis. The mean naming latencies are presented in Table 1. The item means are presented in Appendix A.

In the left-to-right block, the effect of amount of overlap was significant [$F_s(2,34) = 5.53$; $F_i(2,106) = 3.16$]. The 12-msec difference between the one-letter overlap and the control conditions was significant for subjects [$F_s(1,17) = 4.71$] and approached significance for items [$F_i(1,53) = 3.61$, $p = .06$]. The 15-msec difference between the two-letter overlap and the control conditions was significant [$F_s(1,17) = 10.68$; $F_i(1,52) = 5.64$]. The 3-msec difference between the one-letter and the two-letter overlap conditions was nonsignificant [$F_s(1,17) = 1.20$; $F_i(1,52) < 1$].

In the right-to-left block, the effect of amount of overlap was nonsignificant [$F_s(2,34) = 1.12, p = .34$; $F_i(2,106) < 1$]. None of the pairwise contrasts were significant [$F_s(1,17) < 1$; $F_i(1,53) < 1$] in all cases, *except* for the comparison between the two-letter overlap and control [$F_s(1,17) = 2.22$; $F_i(1,53) = 1.30$].

The percent error rates are also presented in Table 1. In the left-to-right block, the main effect of the amount of overlap was nonsignificant [$F_s(1,17) = 2.38, p = .11$; $F_i(2,106) = 1.30$]. None of the pairwise contrasts were significant *except* the comparison between the two-letter overlap and the control, which reached significance in the subjects analysis [$F_s(1,17) = 4.14, p = .05$] but not the items analysis [$F_i(1,53) = 2.26$]. In the right-to-left block, the main effect of the amount of overlap was nonsignificant [$F_s(1,17) = 1.13$; $F_i < 1$]. None of the pairwise contrasts reached significance, with $F < 1$ in all cases *except* for the comparison between the one-letter overlap and the control [$F_s(1,17) = 2.22, F_i(1,53) = 1.25$].

The main finding of this experiment was that a masked prime sharing a grapheme/phoneme with a nonword target facilitated naming of the target *only* if the overlap was in the initial position (e.g., *suf*–SIB), and not if it was in the final position (e.g., *mub*–SIB). This result is therefore consistent with the original interpretation of the masked onset priming effect, suggested by Forster and Davis (1991), that the effect reflects a left-to-right sequential naming process within the nonlexical route, and it is inconsistent with the alternative possibility that it reflects position-independent letter priming.

EXPERIMENT 2

Results of Experiment 1 showed that the masked onset priming effect indeed reflected a sequential process. Before one accepts the finding in terms of a dual-route framework as evidence of a sequential nature of the nonlexical phonological computation process, one alternative interpretation must be considered. Specifically, the naming task involves not only the computation of phonology from orthography, but also an articulatory motor programming component that occurs subsequent to this process. It may be that the sequential effects found with naming latency reported here reflect the nature of this articulatory motor component, rather than the computation of phonology from orthography. After all, articulatory responses are necessarily sequential in that initial segments must be uttered in real time before later segments. Earlier, Grainger and Ferrand (1996) took the fact that masked onset priming effects are not observed with the lexical decision task to argue for such an interpretation.

Models of visual word recognition have generally been silent about this process of generating an articulatory motor program from computed phonology. In fact, the assumption implicit in many models of visual word recognition is that articulation can start as soon as the phonology for the item is computed. In the area of speech production, however, there is recognition that computation/retrieval of phonology is not sufficient for generating an utterance. Levelt and his colleagues (Levelt, 1992; Levelt & Wheeldon, 1994) have been strong proponents of this view and have described a process that they call *phonological encoding* as a necessary step intervening between the computation of an abstract phonological form and the production of an utterance.

In brief, the phonological encoding process involves the decomposition of an abstract phonological word form retrieved from the mental lexicon into a metrical frame (which contains information such as the number of syllables in the word, as well as its accent structure) and phonemic segments, and the assembly of these two pieces of information (segment-to-frame association). Levelt

(1992) pointed out the need for what appears to be an unnecessary step of decomposing a phonological code only to combine them again. He pointed out that in generating connected speech, speakers do not concatenate "citation forms" (the forms retrieved from the mental lexicon) of words, but create rhythmic, pronounceable metrical structures that largely ignore lexical boundaries. (The need for the metrical frame for phonological words may be appreciated by comparing natural speech with the flatness of synthesized speech.) The domain of syllabification, then, is not lexical words, but phonological words (in a task requiring the utterance of a single word, the two are obviously identical). According to Levelt, then, the purpose of decomposing a phonological code is to create metrical frames for *phonological words*, which can then be filled with the segmental information.

There is evidence in the speech production literature that the phonological encoding process occurs left to right, across segments. For example, Meyer (1991) used an implicit priming paradigm in which subjects were required to utter just one word from a list that either shared or did not share segments (e.g., *hut, heel, hop* vs. *hut, dance, pole*). The shared segment was either the onset or rime. Facilitation in production latency was found only when the words shared the initial segments; sharing the rime did not result in any facilitation. Meyer interpreted the result to suggest that phonological encoding of a word proceeds from left to right and that later segments cannot be prepared until the initial segments are selected.

Other evidence from the speech production literature suggests why priming the onset would produce greater facilitation than would priming other subsyllabic segments. It is well known in the observation of speech errors that exchanges of onsets (e.g., *darn bore–barn door*) are much more common than exchanges of other constituents. The accepted explanation of this effect is that onsets of syllables are structurally distinct within a phonological frame and are therefore more detachable than the other sounds, which are more buried in the hierarchical structure of the word (e.g., Dell, Juliano, & Govindjee, 1993). If it is the case that at the subsyllabic level on onset has a more defined role as a constituent than as a nucleus or a coda, it is possible that when an articulatory code for a syllable needs to be constructed from phonological constituents, priming the onset might produce more facilitation than priming other constituents would. The present findings are therefore entirely consistent with this speech production view. Furthermore, it was observed that in the left-to-right overlap block, increasing the overlap from one to two letters (e.g., *suf*–SIB vs. *sif*–SIB) did not produce the same amount of facilitation as did increasing the overlap from no letters to one letter (e.g., *mof*–SIB vs. *suf*–SIB). This finding is inconsistent with the strictly sequential assumption originally put forward by Forster and Davis (1991), but it is compatible with the view that onsets have a special role in speech production relative to those of other constituents (in this case, the nucleus). The sequential nature of the masked onset priming effect may therefore reflect a characteristic of speech production in which selection of onset facilitates articulatory planning, rather than the computation of phonology from orthography within the nonlexical route.

The aim of Experiment 2 was to adjudicate between these two possibilities. Specifically, Experiment 2 was designed to test whether masked onset priming is due to the faster computation of the initial grapheme/phoneme, as Forster and Davis (1991) originally suggested, or to the faster encoding of the onset segment. To separate these two possibilities, two types of targets were used: words with simple onset (e.g., PASTE) and words with consonant cluster onset (e.g., BLISS). Each type of target was preceded by either a prime that shared just the first letter (e.g., *penny*–PASTE or *bingo*–BLISS) or a control prime that shared no letter with the target (e.g., *mummy*–PASTE or *solid*–BLISS). It was hypothesized that if masked onset priming was due to the sharing of the initial grapheme/phoneme, the same amount of priming would be observed for the two types of targets. If, on the other hand, the sharing of onset drives the masked onset priming effect, only the simple onset targets (e.g., PASTE) would show priming, not the consonant cluster onset targets (e.g., BLISS).

Method

Design. The present experiment constituted a 2 (target onset type: simple vs. complex) × 2 (prime type: experimental vs. control) factorial design, with both factors manipulated within subjects. The target words had either a simple onset consisting of a single consonant (e.g., PASTE) or a complex onset consisting of two graphemes/phonemes (e.g., BLISS). The experimental primes shared just the first letter with the target (e.g., *penny*–PASTE; *bingo*–BLISS); the control primes did not share any letter with the target in the same position (e.g., *mummy*–PASTE; *solid*–BLISS). The dependent variable was naming latency.

Subjects. Eighteen volunteer first-year Macquarie University students participated in the experiment for course credit. All the subjects were native Australian-English speakers.

Materials. The critical stimulus materials were 56 five-letter low-frequency words used as targets in a naming task. Half of these had a simple onset (i.e., the onset consisted of a single phoneme/grapheme, e.g., PASTE), and the other half, a complex onset (i.e., the onset consisted of two phonemes written with two graphemes, e.g., BLISS). The complex onsets always contained two phonemes; items that started with a single phoneme corresponding to multiple graphemes (e.g., *sh, th*) were not used. Within each target group, items that shared the onset were constructed as pairs (e.g., *paste* and *pouch*). The items were selected from the pool of words in the MRC psycholinguistic database[4] with the constraint that they must be low in frequency (maximum 10 occurrences per million according to Kučera & Francis, 1967) and five letters long and must have at least three "body friends" (i.e., words that share the rime, e.g., *mouse, house, blouse*). The latter constraint was included to maximize the opportunity for observing masked onset priming effects, since another experiment had shown that the masked onset priming effect was greater for words with many body neighbors than for words with few body neighbors (Kinoshita, 1999). The mean frequency of occurrences per million was 4.60 for the simple onset targets and 3.77 for the complex onset words. The mean number of body friends was 5.47 for the simple onset words and 5.73 for the complex onset words. Examples of the prime and target conditions

Table 2
Mean Naming Latencies (RT, in Milliseconds), Standard Deviations (*SD*), and Percent Errors (%E) with Different Masked Primes in Experiment 2

Target Onset Type	Prime Condition	Example	RT	*SD*	%E
Single onset	experimental	*penny*–PASTE	510	22	.8
	control	*mummy*–PASTE	524	26	2.8
Complex onset	experimental	*bingo*–BLISS	501	36	2.4
	control	*solid*–BLISS	504	36	2.4

Note—The means and standard deviations of the reaction times are based on the item analysis.

are shown in Table 2; the items are listed in Appendix B. Within each onset type, the assignment of a target to the two prime conditions was counterbalanced across subjects in such a way that each target was seen by a subject only once; across every pair of subjects, the target was preceded once by the prime that shared the first letter (e.g., *penny*–PASTE) and by the control prime (*mummy*–PASTE). Since the items were constructed in pairs matched on onset, this ensured that the two prime conditions were matched on onset within each target type.

Apparatus and Procedure. The subjects were tested individually, seated approximately 40 cm in front of an NEC Multisync 4FG monitor upon which the stimuli were presented. The 56 prime–target pairs were presented in one block of testing, in a different random order for each subject.

The timing parameters and the instructions to the subjects were identical to those in Experiment 1. Following the instructions, the subjects were given 10 practice trials. The test block then followed, preceded by two initial filler trials that were not included in the analysis.

Results and Discussion

The treatment of outliers and the method of analysis were identical to those of Experiment 1. Naming latencies of the simple onset targets and the complex onset targets were analyzed separately as a function of prime type (shared initial letter vs. all-letter-different control). The mean naming latencies are presented in Table 2. The item means are presented in Appendix B.

For simple onset targets, the 14-msec effect of prime type was significant [$F_s(1,17) = 6.08, p = .02$; $F_i(1,27) = 5.53, p = .03$]. In contrast, for complex onset targets, the 3-msec effect was nonsignificant [$F_s(1,17) < 1.0$; $F_i(1,27) < 1.0$].

The percent error rates are also presented in Table 2. The effect of prime type approached, but did not reach, significance for the simple onset targets [$F_s(1,17) = 3.46, p = .08$; $F_i(1,27) = 2.39, p = .13$]. There was no effect of prime type for the complex onset targets [$F_s < 1.0$, $F_i = 1.0$].

The main finding from Experiment 2 was that reliable facilitation due to the overlap of just the initial grapheme/phoneme was observed with simple onset targets (e.g., *penny*–PASTE) but not with complex onset targets (e.g., *bingo*–BLISS). Such a finding is at odds with the notion that the unit underlying the masked onset priming effect is a letter (or a grapheme/phoneme), as has been suggested by the DRC model (e.g., Coltheart & Rastle, 1994), but is consistent with the speech production view that the unit corresponds to the onset of a word.

GENERAL DISCUSSION

The findings may be summarized as follows: Experiment 1 showed that in the naming of nonwords, the benefit in naming latency due to the sharing of a grapheme/phoneme between a masked prime and a target was observed only when the overlap was in the initial position. Experiment 2 showed that this priming effect with the initial grapheme/phoneme was reliable only with simple onset targets that had a single consonant as onset (e.g., PASTE) and not with complex onset targets that had consonant clusters as onsets (e.g., BLISS). The results of Experiment 1 confirmed Forster and Davis's (1991) claim that the masked onset priming effect reflects a sequential, left-to-right ordered process. Experiment 2, however, suggested that this sequential nature of the effect can be interpreted better in terms of a speech production process that takes the onset as a unit of articulatory planning than as a characteristic of the nonlexical phonemic computation route within dual-route frameworks of reading. That sequential effects in naming reflect the nature of articulatory planning, rather than the computation of abstract phonology, fits well with the observation that the onset effect is found only with the naming task, and not with other tasks that do not require articulation, such as the lexical decision task (Forster & Davis, 1991; Grainger & Ferrand, 1996).

One aspect of the masked onset priming effect that seems to be at odds with the present articulatory explanation is the observation that it is found with nonwords but not with high-frequency words or exception words (Forster & Davis, 1991, Experiments 4 and 5). Because these words are assumed to be named via the lexical route, this finding provided the rationale for attributing the masked onset priming effect to the nonlexical route. However, it is possible to provide an account of this pattern within the articulatory view, as will be described below.

In converting a phonological code into an articulatory motor program, it is necessary to compute or access articulatory gestures (e.g., "close the lips") that will realize a phonological word's syllables. The implicit assumption common to most current models of visual word recognition is that these gestural scores are simply read out from the string of phonemes computed from the orthographic input. Researchers in the area of speech production (e.g., MacNeilage, 1970) have been aware of one problem with such phoneme-based assumptions of speech production, however—namely, that the actual movements of the articulatory apparatus corresponding to the same phoneme vary, depending on context (i.e., allophonic variation). Therefore, articulatory gestures are not constructed phoneme by phoneme from a string of phonemes.[5] Levelt and Wheeldon (1994) have pointed out that this problem of allophonic variation disappears when a larger unit (e.g., a syllable or a demi-syllable) is considered as the unit of articulation. Furthermore, for syllables that are used regularly in language, the gestural scores for the syllable may be overlearned. Levelt (1992; Levelt & Wheeldon, 1994) therefore suggested the possibility that articulatory gestures for some of the syllables may be retrieved as a whole. The idea is that much like a mental lexicon that stores information about words that are in the speaker's vocabulary, there is a "mental syllabary" that stores the articulatory gestures associated with a finite set of syllables that are regularly used in speech. Like retrieval of words from the mental lexicon, retrieval of articulatory gestures from the syllabary is assumed to be frequency sensitive. It is further assumed that for syllables whose gestural scores are retrieved whole from the mental syllabary, segmental complexity (e.g., the number of phonemes) is expected to have little effect because these segments are packed into a unitized routine.

Because Forster and Davis (1991) used monosyllabic words, their high-frequency word stimuli would have been commonly occurring syllables and would likely have been represented in the mental syllabary. Because the articulatory gestures for these items are packed into a unitized routine, priming just a segment is unlikely to result in much facilitation. The absence of an onset priming effect for high-frequency words (high-frequency syllables) therefore falls naturally out of the mental syllabary framework. It is less clear why exception words (e.g., AISLE, FETE) did not show masked onset priming effects. However, note that the syllable in question refers to a phonological syllable and not its orthographic representation. An inspection of the list of exception words used by Forster and Davis (1991, Experiment 4) indicates that in quite a few cases they were homophones (e.g., *aisle/isle*, *fete/fate*) or homophonous with commonly occurring syllables (e.g., *gauge/gage* in engage). This may have increased the frequency of the phonological syllable, thereby enhancing the opportunities for being represented in the mental syllabary. Clearly, this explanation depends on the selection of the exception stimuli and needs to be tested in the future.

A final comment is in order regarding the issue of when the subjects start articulating in a naming task. Traditionally, researchers have assumed that in speeded naming, subjects initiate articulation as soon as an articulatory motor program is generated for a whole word. Recently, however, Kawamoto, Kello, Jones, and Bame (1998) have argued instead that subjects may initiate articulation on the basis of having computed just the initial phoneme. They suggested that the activation of phonemes rise in parallel, and that subjects initiate articulation as soon as the initial phoneme activation reaches a threshold. This approach predicts exactly the pattern observed in Experiment 1—namely, that priming is obtained only with the initial phoneme and not the other segments because initiation of articulation is assumed to depend only on activation of the initial phoneme.

The finding that motivated the proposal of the initial phoneme criterion is that the regularity effect for second phonemes is reduced for nonplosive-initial words (e.g., *sew*) relative to plosive-initial words (e.g., *pint*). The release of energy that accompanies the initial phoneme (which triggers the voice key) must await the computation of the following phoneme for plosives, but not for nonplosives. Kawamoto et al.'s (1998) argument is that the irregularity of orthography to phonology mapping will slow down the computation of the critical phoneme in both cases, but if the initiation of articulation is based on the computation of the initial phoneme only, the regularity of the second phoneme would have little impact on nonplosive-initial words, which can be articulated without one's waiting for the second phoneme. The regularity × plosivity interaction observed by Kawamoto et al. is therefore exactly what would be expected from the initial phoneme criterion assumption.

The initial phoneme criterion assumption is clearly incompatible with the theoretical framework of articulation adopted here. The idea that subjects initiate articulation as soon as they compute the initial phoneme without knowing the phonological structure for the remainder of the word is directly opposed to Levelt's (1992) framework described here, for it suggests that subjects initiate articulation without knowing the metrical structure of the word. In addition, the initial phoneme criterion assumption would also have trouble explaining the results of Experiment 2, in which priming the initial phoneme did not facilitate naming of words with complex onsets. Against this, Kawamoto et al. (1998) could argue that initial phoneme priming may not be observed for plosives. Although it is the case that some of the complex onset targets had plosive phonemes, in fact, the same number of the simple onset targets and complex onset targets had plosive initial phonemes. The list of items shown in Appendix B also indicates that the presence/absence of the priming effect did not depend on the plosivity of the initial phonemes. Finally, the initial phoneme criterion is also at odds with a number of empirical observations about naming, including the effect of word length observed with naming latency. Indeed, word length was reported by Spieler and Balota (1997) as one of the primary predictors of naming latency in a large-scale multiple regression study. Such a finding is unexpected from the view that the subjects initiate articulation on the basis of having computed just the initial phoneme. Phenomena such as allophonic variation and anticipatory coarticulation effects (e.g., the lip protrusion in articulating the vowel of *spoon* extends to the initial phoneme /s/) also argue against the possibility that subjects initiate articulation on the basis of having computed just the initial phoneme.[6]

Instead of the initial phoneme criterion, the plosivity × regularity interaction reported by Kawamoto et al. (1998; see also Cortese, 1998, for a replication of this finding) may be explained within the whole-word criterion framework as reflecting the sequential nature of articulatory *planning*, rather than the *execution* of an articulatory program. As mentioned earlier, Meyer (1991) interpreted the results of her implicit priming study described earlier in terms of a view that later segments (e.g., rime) cannot be selected for articulatory planning until the early segments (e.g., onset) are selected. Within this view, it may be suggested that because articulatory gestures for plosives depend on subsequent phonemes, their selection is delayed until the ambiguity associated with the irregular phoneme is resolved.[7]

In conclusion, the results presented here suggest that the masked onset priming effect indeed reflects a sequential process, as originally suggested by Forster and Davis (1991). However, the locus of this effect is likely to be in the planning of articulation, rather than the computation of phonology from orthography. Other sequential effects, such as the position-dependent regularity effect (Coltheart & Rastle, 1994; Cortese, 1998), and the length × lexicality interaction (Weekes, 1997) may also have their locus in the planning of articulation. It is suggested that interpreting these effects as evidence for serial computation of phonology may be premature, and that the parallel-versus-serial debate would benefit from consideration of the speech production literature.

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NOTES

1. More recently, another computational model of word recognition has been proposed by Ans, Carbonnel, and Valdois (1998). This model shares the assumption of dual-route models in that it assumes the involvement of a global procedure using knowledge about entire words and an analytic procedure based on the activation of word syllabic segments. Although the analytic procedure is assumed to operate sequentially, from left to right, given that the size of the segment corresponds to a syllable and not a phoneme, it remains to be seen whether this model can simulate the masked onset priming effect.

2. In the original study by Forster and Davis (1991), the prime–target pairs always shared the initial single consonant onsets (as in *save*–SINK). It is not clear from this whether the relevant shared component is (1) the onset of a syllable (e.g., *save*–SINK but not *and*–ASK); (2) the initial consonant cluster (e.g., *star*–STUB but not *star*–SINK); (c) the initial grapheme (e.g., not *kite*–CALL); (4) the initial phoneme (e.g., not *cent*–CALL). The issue of whether the critical unit of overlap is the onset or the initial letter (Case 2, and indirectly, Case 1) will be addressed in Experiment 2 of this paper. The issue of whether it is the initial grapheme, or phoneme overlap (Cases 3 and 4) is currently being investigated by Davis and colleagues.

3. Details of this system can be obtained at the Web address http://u.arizona.edu/~kforster/dmastr/dmastr.htm.

4. Details of this system can be obtained at the Web address http://www.psy.uwa.edu.au/uwa_mrc.htm.

5. Clearly, the fact that people can generate pronunciation for novel combinations of phoneme strings means that under some circumstances it must be possible to construct an articulatory code phoneme by phoneme. It should be emphasized that speech production models such as that of Levelt's (1992) are concerned primarily with explaining the production of words in natural speech, rather than the utterance of nonwords. Note also that this perspective is consistent with the lexicality × length interaction (i.e., the reduced-length effect observed with words, particularly with high-frequency words relative to nonwords) reported by Weekes (1997), because it suggests that for words, the articulatory gestures are packed into a unitized routine, obviating the necessity to construct the articulatory code phoneme by phoneme.

6. Kawamoto et al. (1998) acknowledged that anticipatory coarticulatory effects are a problem for the initial phoneme criterion assumption, but suggested that initiation of articulation may be based on whole-word phonology in natural speech only under nonspeeded conditions. They suggested that when subjects are instructed to respond as quickly as possible, as in a speeded naming task, the criterion is based on the initial phoneme. From this perspective, it may be expected that anticipatory coarticulation effects may disappear in a speeded naming task. Contrary to this prediction, however, Rastle, Harrington, Coltheart, and Palethorpe (in press) found clear anticipatory coarticulation effects in a speeded naming task.

7. This interpretation of the plosivity × regularity interaction assumes that the locus of the regularity effect is late. Specifically, it is assumed to be in the stage of articulatory planning rather than computation of phonology. Such an assumption is compatible with a view of phonology recently proposed by Frost (1998), who argued that the phonological representations computed from orthography in different experimental conditions (e.g., in the lexical decision task and the naming task) differ in the level of specification. The suggestion that the phonological representation tapped by the lexical decision task is underspecified explains why a regularity × plosivity interaction, or even the regularity effect itself, was absent in the lexical decision task (cf. Cortese, 1998).

APPENDIX A
Items Used in Experiment 1

For each item, the naming latencies are listed in the following order: one-letter overlap, two-letter overlap, and control.

Left-to-Right Overlap

bol	597	558	536	cef	625	570	573	dis	556	526	517
fec	618	578	571	gik	618	563	534	hab	519	599	543
jod	554	480	501	kag	532	538	522	lof	583	508	550
mup	569	510	495	nuc	598	509	542	pum	590	568	615
rul	607	531	545	sen	532	469	543	teg	563	500	520
vom	597	557	597	wot	550	541	510	yub	564	536	525
bip	510	569	573	cig	531	600	628	dem	523	532	535
fas	540	579	572	gim	588	607	570	hon	524	532	579
juf	578	566	539	kes	546	518	520	lil	513	587	541
mel	491	539	509	nad	500	528	499	pog	507	534	551
ric	525	584	527	sib	485	530	487	toc	555	528	484
ved	538	559	569	wal	497	599	573	yop	528	507	562
bif	550	516	575	cug	579	556	639	dap	501	527	584
fam	571	556	591	gac	608	566	614	hud	530	567	582
jat	491	504	561	kos	543	559	596	lan	495	523	549
maf	489	499	614	nak	492	475	562	peb	541	511	599
rep	552	549	546	sut	494	520	524	tid	486	489	559
vek	545	600	575	wob	548	483	532	yit	528	541	618

Right-to-Left Overlap

baf	559	577	516	ceg	586	634	604	dep	534	526	532
fic	594	612	580	gud	612	572	543	hed	563	575	539
jeb	607	559	545	kag	588	594	515	lis	539	512	500
mol	522	546	531	nal	569	501	546	pos	554	538	539
rel	579	519	543	sab	545	512	512	tof	565	532	543
vit	564	568	563	wup	561	612	524	yug	567	592	539
bem	525	563	540	cim	594	525	566	dac	526	533	552
fet	542	553	552	gam	563	604	582	hig	560	587	560
jum	520	558	565	kif	554	552	524	lon	546	597	496
min	501	491	510	nuf	547	540	522	pef	517	542	626
ril	505	535	570	sop	476	505	488	tul	573	574	567
vot	581	621	584	wec	539	511	557	yik	544	574	563
bom	506	556	591	cek	619	543	639	dib	547	509	557
fap	534	592	594	gad	576	518	558	hes	515	569	580
jid	567	502	580	kus	608	505	577	lat	580	523	558
mip	509	533	556	nub	550	531	601	poc	516	547	594
ren	508	501	498	san	512	518	531	tob	503	487	510
vak	581	584	614	wut	573	516	595	yas	568	514	564

APPENDIX B
Items Used in Experiment 2

For each item, naming latencies are listed in the following order: experimental prime, control prime.

Simple Onset Items

mouse	462	498	paste	509	536	taunt	496	534
pinch	470	537	hinge	539	544	fetch	537	553
lance	467	515	budge	539	511	weave	478	514
notch	483	562	pants	519	511	barge	515	522
beast	518	518	mirth	522	523	munch	526	550
pouch	533	531	taint	519	477	peach	536	500
hound	523	525	feast	503	485	ledge	488	502
batch	501	496	witch	536	517	noose	506	540
poach	511	606	beech	508	517	boast	523	545
midge	502	532						

Complex Onset Items

flask	502	532	bliss	516	509	snort	437	455
glean	557	562	flute	514	588	stair	448	481
brisk	529	510	graft	504	524	scant	487	467
skull	502	459	prune	525	524	bribe	500	541
swirl	436	477	grief	505	538	flirt	536	546
brunt	559	496	spoil	472	465	grind	519	505
fleck	544	460	stool	457	485	brute	515	542
groom	485	504	swipe	432	463	speck	464	470
probe	520	502	broth	530	549	smirk	507	469
groin	528	492						

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