# Naming Multisyllabic Words

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The process of reading multisyllabic words aloud from print was examined in 4 experiments. Experiment 1 used multisyllabic words that vary in terms of the consistency of component spelling-sound correspondences. The stimuli were regular, regular inconsistent, and exception words analogous to the monosyllabic items used in previous studies. Both regular inconsistent and exception words produced longer naming latencies than regular words. In Experiment 2 these differences between word types were found to be limited to lower frequency items. Experiment 3 showed that effects of number of syllables on naming latency are also limited to lower frequency words. In the final experiment, consistency effects were obtained for both higher and lower frequency words when the stimulus display forced subjects to use syllabic units. Thus, frequency modulates the effects of two aspects of lexical structure—consistency of spelling-sound correspondences and number of syllables. The results suggest that the naming of multisyllabic words that some some of the same knowledge representations and processes as monosyllabic words; however, naming does not require syllabic decomposition. The results are discussed in the context of current models of naming.

The process of reading words aloud from print has been investigated in many studies (see Carr & Pollatsek, 1985; Henderson, 1982; Seidenberg, 1985, for reviews). The complexity of the naming task, and much of its interest, derives from properties of the English orthography. As an alphabetic orthography, written English systematically encodes information about pronunciation; however, the correspondences between spelling and pronunciation are inconsistent, as illustrated by minimal pairs such as have-gave, give-dive, saidpaid, and what-that. This aspect of the writing system has raised questions as to how readers represent knowledge of spelling-sound correspondences, how they cope with irregular instances, and how this knowledge is used in pronouncing unfamiliar stimuli such as nonwords. The task is interesting for two other reasons as well: first, because learning to pronounce words aloud plays an important role in learning to read (Perfetti & McCutcheon, 1982; Stanovich, 1986), and second, because dyslexia following brain injury is often associated with impairments in word naming (Patterson, Marshall, & Coltheart, 1985). Several models of the naming process have been proposed (e.g., Brown, 1987; Glushko, 1979; Coltheart, 1978, 1987), and Seidenberg and McClelland (1989) have developed a computational molel that simulates a broad range of naming phenomena.

Although a great deal is known about the naming process, a serious limitation of previous work is that it has been largely

concerned with the processing of monosyllabic words. There have been many studies of more complex words (e.g., Seidenberg, 1987; Spoehr & Smith, 1973; Taft, 1979; Taft & Forster, 1976) in which the primary goal was to determine whether words are recognized by recovering subword units such as syllables or morphemes. There has also been a large amount of linguistic research directed at developing theories of the sound structure of English, with special emphasis on the rules that govern the pronunciation of multisyllabic words (e.g., Chomsky & Halle, 1968; Liberman & Prince, 1977). However, relatively little is known about the processes involved in generating the pronunciations of complex words from their written forms (see, however, Cutler & Clifton, 1984; Frederiksen & Kroll, 1976). The present research addressed whether some of the generalizations that have emerged from studies of monosyllabic words also apply to more complex words.

Many studies of monosyllabic words have addressed whether the inconsistent spelling-sound correspondences characteristic of English affect the naming performance of skilled adult readers. The general strategy in these studies (e.g., Andrews, 1982; Baron & Strawson, 1976; Bauer & Stanovich, 1980; Brown, 1987; Parkin, 1984; Seidenberg, Waters, Barnes, & Tanenhaus, 1984; Waters & Seidenberg, 1985) has been to examine naming latencies for words that differ in terms of the consistency with which component spelling patterns are associated with particular pronunciations. Typically, consistency has been defined in terms of subword components termed word-bodies (Patterson & Coltheart, 1987), although other aspects of word structure are also relevant to naming (Kay, 1987; Seidenberg & McClelland, 1989; Taraban & McClelland, 1987). Word-bodies are analogous to the rime components of spoken syllables (Treiman & Chafetz, 1987). They vary in the number of ways they are pronounced and the relative frequencies of the pronunciations. Consistent word-bodies are associated with a single pronunciation (e.g., -ust, as in must); inconsistent word-bodies are associated with different pronunciations in different words. Words containing these patterns have been further broken down into subtypes

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according to the relative frequencies of their pronunciations. For example, the pattern -ave is typically pronounced as in gave but is inconsistent because of the word have. Gave-type words have been termed regular inconsistent (Glushko, 1979), and have-type words exceptions (Baron & Strawson, 1976; Bauer & Stanovich, 1980). The pattern -own is also inconsistent, but each of its alternative pronunciations occurs in a large number of words; this type has been termed ambiguous (Backman, Bruck, Hébert, & Seidenberg, 1984). Patterns such as -ust and -oap are both consistent in that they are associated with a single pronunciation in monosyllabic words; they differ, however, in frequency: There are a large number of -ust words but only one containing -oap. The former have been termed regular or consistent words, and the latter unique (Brown, 1987).

The empirical studies of such words have yielded a clear generalization: The effects of inconsistent spelling-sound correspondences on naming depend on word frequency. For higher frequency words, this aspect of word structure has little impact on performance. Thus, all of the word types listed above yield similar naming latencies when they are equated in terms of other factors such as length. For lower frequency words, latencies depend on the number of alternative pronunciations associated with a spelling pattern and their relative frequencies. Consider, for example, the contrast between regular words such as must and exceptions such as have. For items that are relatively low in frequency, exception words (e.g., *broad*) yield longer naming latencies than regular words (such as breed). For higher frequency words, however, differences between the two types are much smaller and usually not reliably different from zero (Andrews, 1982; Seidenberg et al., 1984; Taraban & McClelland, 1987; Waters & Seidenberg, 1985).<sup>1</sup>

Seidenberg and McClelland (1989) developed a computational model that simulates the results of a large number of studies examining these types of words. In this parallel distributed processing model, facts about the correspondences between spelling and pronunciation are encoded by the weights on connections between simple processing units. The values of the weights were set during a learning phase in which the model was exposed to a large number of monosyllabic words and their pronunciations. The weights are affected by the number of times the model is exposed to a spelling pattern and by the consistency of its pronunciation. In general, the model performs better on words with consistent pronunciations; repeated exposure to a spelling pattern with a particular pronunciation pushes the weights in a direction that improves performance. Words containing inconsistent patterns fare more poorly because the weights reflect the aggregate effects of training on the alternative pronunciations, which shifts the weights in competing directions. Finally, the effects of inconsistent spelling-sound correspondences are smaller for higher frequency words because of repeated exposures to the words themselves. Whereas the model performs more poorly on a lower frequency exception word such as lose than on a comparable regular word such as lobe, it performs about equally well on higher frequency regular and exception words such as must and have. As Seidenberg and McClelland show, the model closely simulates the results of a large number of behavioral studies using many types of words.

This research raises several issues in regard to more complex, multisyllabic words. One is whether the characterization of readers' knowledge of spelling-sound correspondences that has emerged from studies of monosyllabic words is relevant to more complex words. Clearly the pronunciation of multisyllabic words involves processes that go beyond those required for monosyllabic words-for example, the assignment of syllabic stress and the systematic reduction of unstressed syllables. The question to be addressed is whether the characterization of spelling-sound knowledge in terms of consistency and frequency derived from consideration of monosyllabic items generalizes to the much larger pool of multisyllabic words. Although it is clear that pronouncing multisyllabic words involves factors that are not relevant to monosyllabic words, it is not known whether the factors that influence the processing of monosyllabic words contribute to multisyllabic ones.

Aside from its relevance to understanding how readers pronounce complex words, we were interested in this question because there are methodological limitations in the studies of monosyllabic words that can be addressed by considering multisyllabic items. Words vary simultaneously along several dimensions such as frequency, orthographic redundancy, length, regularity or consistency of pronunciation, and others. The general strategy in previous research has been to equate stimuli along several of these dimensions in order to examine the effects of one or two. For example, in comparing regular and exception words, researchers attempted to identify the effects of one variable (a particular type of regularity in terms of spelling-sound correspondences) against the background of noise provided by all other aspects of word structure, which they attempted to control in selecting their stimuli. Taken with the fact that there is a limited number of monosyllabic words in the language, the net result was that these studies tended to use small stimulus sets, with many of the same items occurring repeatedly across studies. This has led to some questioning of the generality of the results that were obtained (e.g., Norris & Brown, 1985). The pool of usable items can be expanded greatly by considering multisyllabic items.

Finally, we were interested in testing another generalization that has emerged from studies of monosyllabic words: The effects of structural variables are modulated by frequency. As noted earlier, inconsistent spelling-sound correspondences have larger effects on less familiar words; for a large pool of very familiar words, these inconsistencies have no effect. Other aspects of word structure function in a similar manner. For example, Waters and Seidenberg (1985) examined a class of *strange* words containing very low frequency, idiosyncratic spelling patterns; examples include *aisle*, *once*, *beige*, and

<sup>&</sup>lt;sup>1</sup> Brown (1987) has argued that exception words differ from regular words not because their pronunciations are irregular, but because they occur less frequently. This issue can be ignored in the present context because all models (Brown's, 1987; Seidenberg & Mc-Clelland's, 1989; the dual-route model, Coltheart, 1978; and Glushko's, 1979, analogy model) predict longer latencies for exception words than regular. However, Seidenberg, McRae, and Jared (1988) provide evidence that both the consistency and frequency of spellingsound correspondences affect naming, contrary to Brown's account.

tongue. These patterns differ from regular and exception words in terms of orthographic redundancy; patterns such as -eige and -ongue do not occur in many words. Waters and Seidenberg found that this factor also only influenced the processing of relatively low frequency words, an outcome that is also obtained in the Seidenberg and McClelland (1989) model. Thus, variations in the orthographic and phonological properties of words have smaller effects on processing as the frequency or familiarity of a word increase. Our goal was to determine whether the same held true for multisyllabic words. This question was addressed in two ways. First, we examined whether, as in the case of monosyllabic words, effects of inconsistent spelling-sound correspondences in multisyllabic words are related to word frequency. Second, we examined whether the effects of another aspect of word structure, number of syllables, are also modulated by frequency. The latter question is important because previous studies have yielded conflicting results as to whether readers decompose words into syllables (or other sublexical units) as part of the naming or recognition process (see Henderson, 1982, for review). Our hypothesis was that these inconsistent results might be related, in part, to word frequency; perhaps the syllabic structure of words is more relevant to lower frequency items than high. If this were the case, it would provide additional support for the generalization that the effects of structural variables are modulated by frequency; it would also address whether the naming of a word necessarily requires decomposition into syllabic components.

#### Experiment 1

The first experiment examined the effects of inconsistent spelling-sound correspondences on the naming of multisyllabic words. For monosyllabic words, there is a relatively well developed theory of the consistency of spelling-sound correspondences. Consistency has been defined in terms of the relations among a set of neighboring words sharing a given word-body; this aspect of word structure is important because of properties of written English (e.g., the fact that the pronunciations of vowels are more affected by the letters that follow them than the letters that precede them). There is no comparable theory of how multisyllabic words are pronounced from print, and thus there is no theoretically motivated notion of consistency relevant to these items. In this initial study, we addressed the issue of consistency in multisyllabic words by attempting to develop stimuli that were analogous to ones used in previous studies of monosyllabic words. Glushko (1979) and others have examined three types of words: exception (such as *have*), regular inconsistent (such as *gave*), and regular (such as must). We constructed sets of bi- and trisyllabic stimuli containing syllables analogous to these types of words. We first identified minimal pairs of words with the same stress pattern containing a critical syllable that is pronounced in two ways. Examples are rigor/rigid and divine/ ravine. Words were operationally defined as regular inconsistent or exception on the following basis: If the syllable was pronounced as it would be in isolation, it was considered regular inconsistent. If the word was pronounced differently than in isolation, it was termed exceptional. Manelis and Atkinson (1974) used similar criteria in identifying irregularly pronounced syllables. Each word was matched with a control item containing a syllable with a regular and consistent pronunciation in the comparable position (e.g., robber or convene). A syllable was considered regular if it is pronounced the same way in all words with the same stress pattern. Although there are theoretical disagreements about the locations of syllable boundaries in some words (e.g., camel), consistent criteria were used in constructing the different types of stimuli, specifically the syllabifications given by the American Heritage Dictionary of the English Language. The important contrast is between words containing inconsistent syllables (such as rig) and those containing consistent syllables (such as rob). The further division into regular inconsistent and exception was included for exploratory purposes and should be considered very tentative, because the neighborhood concept on which it is based may not be valid for multisyllabic words. As in these examples, the inconsistent syllable either occurred at the beginning of the word or at the end.

# Method

*Subjects.* Twenty-five McGill University undergraduates volunteered to participate in the experiment. All were native speakers of English.

Stimuli. The stimuli were 160 two- and three-syllable English words (Table 1). There were 40 exception/regular inconsistent pairs, such as *rigid/rigor*. In 20 pairs, the inconsistent syllable was in the first syllable, and in 20 pairs it was in the last syllable. Each of the 80 inconsistent words was matched with a word containing a regular syllable in the relevant position (first or last). The inconsistent words and their regular controls were closely equated in terms of Kučera and Francis (1967) frequency, length, initial phoneme, and stress pattern. The four types of inconsistent words were ealso equated in terms of frequency.<sup>2</sup> The words were relatively low frequency items, with means for the eight types of items ranging from 15 to 19 according to the Kučera-Francis count. Most of the critical syllables are nonwords in isolation; the number of syllables that form monosyllabic words was approximately the same across groups.

To avoid possible priming effects from repetitions of spelling patterns with different pronunciations (Seidenberg et al., 1984), the 160 words were divided into two lists. Each list had 20 exception, 20 regular inconsistent, and 40 regular words. Half of the exception and regular inconsistent words on each list had an inconsistent first syllable; the other half had an inconsistent final syllable. The lists were counterbalanced so that each member of a regular inconsistent/ exception pair appeared on a different list. Regular words were placed on the opposite list from the word to which they were yoked. The words occurred in random order on each list.

*Procedure.* Testing occurred in two 15-min sessions separated by at least 1 week. In each session the subject was given 15 practice trials

<sup>&</sup>lt;sup>2</sup> It is known that there are inaccuracies in the frequency norms, especially in the lower frequency range (Gernsbacher, 1984). Moreover, there are individual differences in regard to frequency effects measured against these norms (Seidenberg, 1985). The norms provide a sufficient basis for constructing sets of stimuli that differ greatly in frequency, but caution must be observed when equating different groups in terms of frequency. In constructing the stimuli in all experiments, we used both the Kučera and Francis (1967) and Carroll, Davies, and Richman (1971) norms, which yielded similar results.

Table 1Examples of Stimuli Used in Experiment 1

	Type of word			
Pelayant	Incon	sistent	Regula	r consistent
position	Exc.	Reg. inc.	Exc. match	Reg. inc. match
First syllable	<u>cell</u> ist <u>cho</u> rus	<u>cell</u> ar chosen	<u>cul</u> prit channel	cancer chapter
Last syllable	manger ravine	<u>man</u> gle divine	mentor recite	<u>mum</u> ble dispute
	stomach	spinach	supper	scatter

*Note.* Exc. = exception; Reg. inc. = regular inconsistent; critical syllables are underlined.

followed by 80 experimental trials with words from one of the stimulus lists. Order of lists was counterbalanced across subjects. Subjects were instructed to read each word aloud quickly and accurately when the stimulus appeared on the screen.

The stimuli were displayed in lowercase letters in the center of a video monitor (Amdek Video-300) attached to an Apple II+ microcomputer. Words were presented one at a time and remained on the screen until the subject began to speak into a microphone connected to a voice-operated relay that was connected with the computer. The real-time clock in the computer timed the response latencies in milliseconds from the appearance of the stimulus to the onset of the subject's response. The intertrial interval was 2 s. The experimenter recorded mispronunciation errors by hand.

#### Results

Both latency and error data were analyzed. Reaction times longer than 1,500 ms were counted as errors. Error data were square-root transformed (Myers, 1979). Analyses of variance on the reaction time and error data were performed with both subject and item means as fixed effects;  $F'_{min}$  statistics were calculated and are reported where significant.

The mean naming latencies and percentage errors for the exception, regular inconsistent, and matched regular words are presented in Table 2. Three scores greater than 1,500 ms were counted as errors and 1.3% of the scores were excluded from the analyses because of machine malfunctions (either the voice-key did not pick up the subject's response, or it was triggered by extraneous noise). There were three factors in the analyses of variance, each with two levels: consistency (exception and regular inconsistent vs. matched regular words), type

Table 2

Mean Naming Latencies (in Ms) and Percentage of Errors, Experiment 1

	First syllable		Last syllable	
Word type	M	%	M	%
Inconsistent				
Exception	617	11.4	638	5.8
Reg. inc.	595	3.4	619	8.6
Regular/consistent				
Exc. match	589	0.6	606	3.4
Reg. inc. match	581	0.6	585	0.8

Note. Exc. = exception; Reg. inc. = regular inconsistent.

of inconsistency (regular inconsistent vs. exception), and critical syllable (first vs. last).

In the reaction time data, the main effect of consistency was significant. Subjects took significantly longer to name exception/regular inconsistent words (618 ms) than matched regular words (590 ms),  $F'_{min}(1, 178) = 9.67, p < .01.^3$  Regular inconsistent words and their regular controls (595 ms) also yielded faster naming latencies than exception words and their controls (613 ms),  $F'_{min}(1, 184) = 3.85, p < .05$ .

Two-tailed t tests were performed as planned comparisons of the differences between means. Exception words (628 ms) took longer to read than regular inconsistent words (607 ms) both by subject, t(47) = 4.15, p < .001, and by item, t(152) =2.10, p < .05. The regular inconsistent words, in turn, took significantly longer to read than matched regular words (583 ms) both by subject, t(47) = 4.73, p < .001, and by item, t(152) = 2.43, p < .05. However, the regular words matched to the exception words (598 ms) also took longer to name than the regular words matched to regular inconsistent words (583 ms). This difference was significant by subject, t(47) =3.08, p < .01. Subtracting the naming times for regular words from the matched exception and regular inconsistent words yielded net consistency effects of 30 ms for exception words and 25 ms for regular inconsistent words.

Subjects took longer to name words with an inconsistency in the final syllable (629 ms) than in the first syllable (606 ms); this difference was significant by subject, t(47) = 5.85, p < .001, but not by item, t(152) = 1.29, p > .05. Subjects also took longer to read regular words matched to words with an inconsistent final syllable (595 ms) than regular words matched to an inconsistent initial syllable (585 ms). Again this was significant by subject, t(47) = 2.65, p < .05, but not by item, t(152) = .87, p > .05. When the reaction times for regular words were subtracted from those of the matched inconsistent words, the inconsistency effect was 12 ms larger for words with an inconsistent final syllable.

In the analyses of the error data, only the main effect of consistency was significant. Subjects made more errors on the exception/inconsistent words (7.1%) than on regular words (1.4%),  $F'_{min}(1, 185) = 12.16$ , p < .001. In the two conditions with the highest error rates, exception words with the exception in the first syllable (11.4%) and regular inconsistent words with the inconsistency in the final syllable (8.6%), most of the errors clustered around a few items. The words *modal*, *cellist*, and *manger* accounted for 79% of errors in the first syllable exception condition, and the words *rebut* and *conduit* accounted for 72% of the errors in the final syllable regular inconsistent condition.

#### Discussion

The main finding from Experiment 1 is that, as in the case of monosyllabic words, inconsistencies in spelling-sound correspondences affected the naming of multisyllabic words. The notion of consistency derived from studies of monosyllabic words yielded analogous results for multisyllabic words. This

<sup>&</sup>lt;sup>3</sup> All values given in parentheses are subject means.

outcome suggests that the results of previous studies generalize beyond the limited sets of monosyllabic words that were studied. Both types of inconsistent words yielded longer naming latencies than regular words, and the effects were very similar in magnitude.

The fact that regular inconsistent words yielded longer latencies than regular words is important in the context of current theories concerning the representation of spellingsound knowledge. Several theories using very different types of knowledge representations and processes can account for differences between regular and exception words. In the dualroute model, for example, the exception effect results from a temporary misanalysis because of the application of a pronunciation rule; in Glushko's (1979) model it results from feedback from inconsistent neighbors; in Seidenberg and McClelland's (1989) model, it occurs because the weights on connections between units more strongly encode regular pronunciations than irregular ones. Regular inconsistent words are important because their pronunciations are thought to be correctly specified by the pronunciation rules of English. Hence the view that readers attempt to pronounce words by applying such rules predicts that regular inconsistent words should act like regular words. The other accounts afford the possibility that the pronunciation of a regular inconsistent word could be influenced by knowledge of exception-word neighbors, yielding longer latencies than regular words.

Glushko (1979) reported two studies in which regular inconsistent words (such as gave) and nonwords (such as mave) yielded longer naming latencies than matched regular stimuli. These results have been taken as strong evidence against dualroute models (see, for example, Henderson, 1982). However, these effects have not proved to be robust. Seidenberg et al. (1984) showed that the Glushko results derived in part from repeating spelling patterns with different pronunciations, which results in intralist priming effects. When spelling patterns were not repeated, regular inconsistent words differed from regular words only when they were low in frequency. Taraban and McClelland (1987), however, found no statistically reliable effects for either high- or low-frequency words. Hence it is important that a regular inconsistent effect was obtained in the present study.<sup>4</sup> In summary, regular inconsistent words implicate a notion of *degree* of consistency: Their pronunciations are more consistent than those of exception words but less consistent than those of regular words. These intermediate cases are difficult to explain within dualroute models, which only distinguish between words that obey pronunciation rules and those that do not.

Experiment 2 examined whether the effects of inconsistent spelling-sound correspondences are modulated by frequency, as in the case of monosyllabic words. The stimuli in Experiment 1 were fairly low in frequency, compared with items used in previous studies. Experiment 2 used a larger pool of regular and exception words including both high- and low-frequency items. We again constructed the inconsistent stimuli by identifying words that contain syllables associated with multiple pronunciations. One of the main limitations of this research is that there is no independent theory of *regularity* or *consistency* relevant to multisyllabic words; the distinction between consistent and inconsistent items that we employed

in Experiment 1 was simply operational. The results of this experiment provide evidence that this distinction is capturing an aspect of word structure relevant to naming multisyllabic words, as it did in the case of monosyllabic words. In order to gain some independent evidence that the two types genuinely differ in consistency, rather than some other confounding factor, we also tested the stimuli in Experiment 2 on the Seidenberg and McClelland (1989) model. The model represents a computational account of readers' knowledge of spelling-sound correspondences and the use of this knowledge in naming monosyllabic words. This knowledge is represented in terms of weighted connections between units encoding orthography and phonology. The model takes a spelling pattern as input and yields a pattern of activation across a set of phonemic nodes as output. Performance on any given word (or nonword) is assessed in terms of an error score, calculated by comparing the pattern that the model produces with the target pattern that would be produced if the model performed without error. This error score represents a generalized measure of the regularity or consistency of spelling-sound correspondences based on knowledge of monosyllabic words. As Seidenberg and McClelland show, the magnitudes of these error scores are monotonically related to naming latencies. Thus the model makes quantitative predictions about the relative difficulty of naming different letter strings and, in general, the error scores provide a close fit to behavioral data from many experiments. We tested all of the inconsistent syllables from the stimuli for Experiment 2 on the model, including inconsistent syllables such as chid, taken from the word orchid, and regular syllables such as rect (from correct). Although the model produced plausible output for both types, it yielded significantly larger error scores for the inconsistent syllables. Hence the model provides an additional basis for the prediction that words with inconsistent syllables will be more difficult to name than words with consistent syllables. Note that it is by no means the case that the model captures all of the facts about spelling-sound correspondences relevant to multisyllabic words. The simulation simply suggests that some of the variance associated with naming latencies for multisyllabic words may derive from the use of knowledge gained on the basis of monosyllabic ones.

#### Experiment 2

#### Method

Subjects. Twenty-five McGill University undergraduates were paid \$2 each to participate in the experiment. All were native speakers of English.

Stimuli. The stimuli were 120 two- and three-syllable English words (Table 3). Sixty of the words were relatively high in frequency;

<sup>&</sup>lt;sup>4</sup> Seidenberg et al. (1988) also report a regular inconsistent effect in a study employing monosyllabic words. They discuss some of the factors that may be responsible for the differing results of studies using regular inconsistent words. The main factor is that the presence of a single exception-word neighbor (e.g., *have* in the set of *-ave* words) is not necessarily sufficient to cause the effect (see also Seidenberg & McClelland, 1989).

Table 3Examples of Stimuli Used in Experiments 2 and 4

Syllable	High-frequency		Low-frequency	
position	Exception	Regular	Exception	Regular
First syllable	island	inside	diesel	dabble
	beauty	broken	cellist	culprit
	danger	dinner	modal	metro
Last syllable	above	along	mocha	molar
	police	provide	jostle	jiggle
	soldiers	silence	corsage	corrode

Note. Critical syllables are underlined.

60 were lower frequency words. The mean frequencies of the two groups of words were 158 and 2, respectively, according to the norms of Kučera and Francis (1967). Half of the words in each frequency group contained syllables with inconsistent spelling-sound correspondences. In this study we did not distinguish between exception and regular inconsistent words. Half of these words had an inconsistent first syllable (e.g., <u>diesel</u>), and half had an inconsistent final syllable (e.g., <u>orchid</u>). The two frequency groups and two locations of inconsistent syllables yielded four sets of inconsistent words. Words in the two high-frequency sets were closely equated in terms of frequency, as were the words in the two low-frequency sets. Each of the 60 inconsistent words was matched with a regular word with the same initial letter and syllable sizes and, across items, in terms of frequency, length, and syllable size. Fifteen additional two-syllable words were chosen to serve as practice stimuli.

*Procedure.* The procedure was similar to that in Experiment 1. Subjects were first given 15 practice trials and then 120 experimental trials in two blocks of 60 words each. Stimuli were presented in a random order. Subjects were instructed to read each word aloud quickly and accurately. The intertrial interval again was 2 s. The experimenter recorded mispronunciation errors by hand.

#### Results

The mean reaction times and percent errors are presented in Table 4. Thirteen scores greater than 1,500 ms were counted as errors, and 0.9% of responses were excluded from the analyses because of machine malfunctions. There were three factors in the analyses of variance, each with two levels: frequency (high vs. low), regularity (exception vs. regular), and syllable of exception (first vs. last).

Subjects took significantly longer to name low-frequency words (688 ms) than high-frequency words (576 ms),  $F'_{min}(1, 105) = 69.01$ , p < .001, and made more errors on low-

Table 4

Mean Naming Latencies (in Ms) and Percentage of Errors, Experiment 2

	High-frequency		Low-frequency	
Word type	M	%	M	%
First syllable				
Exception	580	0.0	731	28.5
Regular	587	0.5	651	2.9
Last syllable				
Exception	560	2.4	696	18.9
Regular	577	0.0	675	6.4

frequency words (14.4%) than on high-frequency words (0.7%),  $F'_{\min}(1, 100) = 39.40$ , p < .001. Subjects also responded significantly faster to regular words (623 ms) than to exception words (642 ms),  $F'_{\min}(1, 145) = 3.96$ , p < .05, and made fewer errors on regular words (2.5%) than on exception words (12.5%),  $F'_{\min}(1, 141) = 23.91$ , p < .001.

There was a significant interaction between frequency and regularity, both in the reaction time data,  $F'_{\min}(1, 142) =$ 9.89, p < .01, and in the error data,  $F'_{\min}(1, 111) = 15.29$ , p < .001. Planned comparisons t tests were performed to assess differences between exception and regular words for both lowand high-frequency stimuli. For low-frequency items, exception words (713 ms) took significantly longer to name than regular words (663 ms) by subject, t(46) = 9.58, p < .001, and by item, t(112) = 4.97, p < .001. Low-frequency exception words (23.7%) also produced significantly more errors than regular words (4.7%) both by subject, t(46) = 13.75, p < .001, and by item, t(112) = 9.13, p < .001. The high error rates for low-frequency exception words were due to four items (viscount, cellist, manger, and giblet) that were incorrectly named by over half the subjects. For high-frequency words, the only significant effect was that in the analysis of the reaction time data by subject, the difference between regular words (582 ms) and exceptions (570 ms) was significant, t(46) = 2.25, p <.05.

The size of the exception effect for low-frequency words depended on whether the exception was at the beginning or end of the word. The exception effect was 80 ms when the first syllable was irregular and 20 ms when the last syllable was irregular. In the latency data, the triple interaction (Frequency × Regularity × Syllable Position) was significant in the analysis by subject, F(1, 24) = 10.40, p < .01, and approached significance in the analysis by item, F(1, 112) = 2.92, .05 < p < .10. In the error data, the triple interaction was significant in the analysis by subject, F(1, 24) = 47.61, p < .001, and marginally so in the analysis by item, F(1, 112) = 3.74, p = .052.

# Discussion

The results of this study indicate that, for multisyllabic words, irregular spelling-sound correspondences only interfered with the naming of low-frequency items. This finding is consistent with previous results for monosyllabic words. In the Seidenberg and McClelland (1989) model, performance on high-frequency words reaches floor levels because of repeated exposure to the items themselves. The results of Experiment 2 suggest that a similar process occurs in the case of multisyllabic words. In contrast to Experiment 1, inconsistent syllables in the initial position produced larger effects than inconsistent syllables in the last position. These findings are difficult to interpret because it is not certain whether the syllables in the first and last positions were similar in terms of degree of consistency. We counted the number of other words (not including inflected forms) with the same critical syllable as each low-frequency exception word. The words with an inconsistent initial syllable averaged 6.3 inconsistent neighbors (enemies; McClelland & Rumelhart, 1981) in which the syllable was pronounced regularly and the words with an

inconsistent final syllable averaged 4.3 enemies. Hence the difference in the magnitude of the consistency effect may be a function of degree of inconsistency rather than syllable position.

The fact that inconsistencies did not interfere with the pronunciation of high-frequency words is compatible with two interpretations. One is that subjects did not decompose these words into syllables; pronunciations were assigned on the basis of entire orthographic patterns. The other is that the words were decomposed into syllables, with pronunciations assigned to each one, but the inconsistencies in the critical syllables had no impact on naming latency, perhaps because they are themselves higher frequency patterns or less inconsistent than the syllables in the low-frequency words. That is, each syllable could act like a higher frequency word in regard to the effects of inconsistent spelling-sound correspondences. These alternatives are important to disentangle, because there have been a number of theories suggesting that the processing of complex words necessarily involves decomposition into syllables (Spoehr & Smith, 1973) or other quasi-syllabic components (e.g., Taft, 1979). Empirical studies have not yielded consistent evidence for decomposition into such units, however (see Andrews, 1986; Henderson, 1982; Lima & Pollatsek, 1983; Seidenberg, 1987; Taft, 1985, 1987). Perhaps this is the case because sublexical units such as syllables are only relevant to lower frequency words, as suggested by one interpretation of the results of Experiment 2.

A number of studies have examined whether the number of syllables in a word is related to naming latency, the core hypothesis being that words with a larger number of syllables should yield longer naming latencies, owing to processes involved in recovering syllabic structure. Eriksen, Pollack, and Montague (1970) presented subjects with monosyllabic and trisyllabic words that were matched so that each monosyllabic word was the first syllable in a trisyllabic word (e.g., cab, cabinet). They found a significant effect of number of syllables on naming latency; however, the number of syllables was confounded with word length. Klapp, Anderson, and Berrian (1973) found a significant effect of number of syllables on the naming of common 5-letter words. However, Forster and Chambers (1973) did not find a syllable effect with 4letter monosyllabic and bisyllabic words, nor did Frederiksen and Kroll (1976) with words of 4-6 letters and 1-2 syllables. Richardson (1976) also failed to find a syllable effect in a study using words of 5-11 letters and 2-4 syllables. This conclusion, however, was based on a post hoc analysis using only 12 multisyllabic items. Butler and Hains (1979) presented words that varied in number of syllables (1-5), number of letters (2-14), and frequency to skilled and less skilled undergraduate readers. A regression analysis indicated that the number of syllables in a word was correlated with naming latency. Studies examining the effects of number of syllables on measures other than naming latency have also yielded inconsistent results (Henderson, 1982; Seidenberg, 1987, 1989), as have studies of other units such as the Basic Orthographic Syllable Structure (BOSS) (Andrews, 1986; Lima & Pollatsek, 1983; Seidenberg, 1987; Taft, 1985, 1987).

In Experiment 3, the hypothesis that the number of syllables in a word is only relevant to lower frequency items was examined by covarying the number of syllables in the stimulus words and their frequencies. It should be noted that three of the studies discussed above (Butler & Hains, 1979; Forster & Chambers, 1973; Frederiksen & Kroll, 1976) examined the effects of both frequency and number of syllables on naming latency but did not report data concerning the interaction of these factors.

# **Experiment 3**

#### Method

Subjects. Twenty-five McGill University students participated in the experiment. All were native speakers of English and were paid \$2 for their participation.

Stimuli. The stimuli were 240 English words (Table 5), 120 highfrequency items (mean Kučera & Francis, 1967, frequency = 125.0) and 120 low-frequency words (mean frequency = 2.3). There were 40 short (6-letter), 40 medium (8-letter), and 40 long (10–11 letter) words. At each length, half of the words had one more syllable than the other half. The short words had either 1 or 2 syllables, the medium words had either 2 or 3 syllables, and the long words had either 3 or 4 syllables. Thus, the design included three factors: frequency (high or low), length (short, medium, or long), and number of syllables (*n* or n + 1).

The stimuli in different conditions were equated in terms of several other factors. The six groups at each level of frequency were matched in terms of overall frequency. Words in the four groups at each length were matched as closely as possible for initial phoneme. The highand low-frequency words at each level of length and number of syllables were also closely matched in terms of syllabic structure and stress. Fifteen additional 6-, 8-, and 10-letter words served as practice stimuli.

*Procedure.* The procedure was the same as in Experiments 1 and 2. Subjects were first shown the 15 practice words and then the 240 experimental words in two blocks of 120 words each. Items were presented in random order.

# Results

The mean naming times and percentage of errors for the 12 groups of words are presented in Table 6. Latencies longer than 1,500 ms (0.5%) were scored as errors, and 1.2% of scores were excluded from the analyses because of machine

Table 5			
Examples of Stimuli	Used in	Experiment	3

	High-fi	requency	Low-frequency		
Length	n syllables	n + 1 syllables	n syllables	n + 1 syllables	
Short	Church	Common	Cruise	Crocus	
	Street	Simple	Stitch	Sonnet	
	Ground	Garden	Grieve	Goblin	
Medium	Approach	Addition	Appraise	Altitude	
	Standard	Specific	Splinter	Sporadic	
	Research	Remember	Rehearse	Receptor	
Long	Production Commission Expression	Population Competition Experiment	Protrusion Compassion Extinction	Paraplegic Collaborate Exposition	

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Table	6		
Mean	Naming Latencies (in	Milliseconds) and	Percentage of
Error	s, Experiment 3		

	High- frequency		Low- frequency	
Word type	M	%	M	%
Short				
1 syllable	562	0.6	587	0.2
2 syllables	566	2.4	609	1.8
Medium				
2 syllables	554	0.2	594	0.6
3 syllables	567	0.8	628	2,2
Long				
3 syllables	590	0.6	645	4.0
4 syllables	592	0.6	687	6.0

malfunctions. There were three factors in the analyses of variance, frequency (high or low), length (short, medium, or long), and number of syllables (n or n + 1).

As in previous experiments, subjects took longer to name low-frequency words (625 ms) than high-frequency words (572 ms),  $F'_{min}(1, 58) = 33.00$ , p < .001. There was also a significant effect of length,  $F'_{min}(2, 101) = 15.17$ , p < .001. The mean naming latencies were 581, 586, and 628 ms for the short, medium, and long words, respectively. There was an interaction between frequency and length by subject, F(2,48) = 19.06, p < .001, and by item, F(2, 228) = 3.89, p <.02. The length effect was smaller for high-frequency words (Ms = 564, 561, and 591 ms for short, medium, and long words, respectively) than for low-frequency words (Ms = 598, 617, and 666 ms, respectively).

In addition, there was a main effect of number of syllables,  $F'_{\min}(1, 125) = 7.82, p < .01$ , with subjects naming words with n syllables (588 ms) more quickly than those with n + 1syllables (608 ms). The interaction between frequency and number of syllables was also significant,  $F'_{min}(1, 243) = 4.08$ , p < .05. The net difference between the n and n + 1 stimuli was 6 ms for high-frequency words and 33 ms for lowfrequency words. Planned comparisons for the low-frequency words yielded significant differences between the n and n + 1conditions for short words (22 ms), t(59) = 2.65, p < .02 by subject and t(228) = 1.79, .05 by item; for mediumwords (34 ms), t(59) = 3.99, p < .001 by subject and t(228) =2.63, p < .01 by item; and for long words (42 ms), t(59) =4.94, p < .001 by subject and t(228) = 2.79, p < .01 by item. None of the syllabic effects for high-frequency words approached significance.

In the error data, there was a main effect of frequency,  $F'_{\min}(1, 53) = 7.31$ , p < .01. Subjects made more errors on low-frequency words (2.5%) than on high-frequency words (0.9%). Almost half of the errors on high-frequency words were due to one item, *county*. There was also a significant effect of length,  $F'_{\min}(2, 81) = 4.77$ , p < .02. Long words produced more errors (2.8%) than medium words (1.0%) or short words (1.3%). There was a significant interaction of frequency and length,  $F'_{\min}(2, 113) = 7.14$ , p < .01, which was due to the relatively high error rate for low-frequency long words (5%) compared with all other words (all less than

1.5% errors). Finally, there was a main effect of syllables,  $F'_{\min}(1, 74) = 4.80, p < .05$ . Subjects made fewer errors on words with n syllables (1.0%) than on words with n + 1 syllables (2.3%). The interaction between frequency and syllables was not significant.

The results indicate that the number of syllables in a word influenced naming latencies only for low-frequency words. The difference between low-frequency 1- and 2-syllable words was 22 ms, the difference between 2- and 3-syllable words was 34 ms, and the difference between 3- and 4-syllable words was 42 ms, suggesting that the size of the syllable effect increased as a function of number of syllables. Among the high-frequency items, number of syllables had no reliable effect even for the longest words. The modulation of the effect of number of syllables by frequency mimics the effects for spelling-sound consistency obtained with both monosyllabic (Andrews, 1982; Seidenberg et al., 1984; Taraban & Mc-Clelland, 1987) and multisyllabic words (Experiment 2). For high-frequency words, only length influenced naming latencies.

#### Discussion

Experiments 2 and 3 provide two sources of evidence suggesting that syllabic structure is only relevant to the processing of lower frequency words. In Experiment 2, inconsistent spelling-sound correspondences within a syllable only affected the processing of low-frequency words. In Experiment 3, number of syllables was related to naming latency only for low-frequency words. In Experiment 4, we examined this issue in another way, replicating Experiment 2 with a change in procedure: The method of stimulus presentation forced subjects to use syllabic units. Subjects were again required to name the words aloud, but the syllables in each word were presented in sequence. The rationale for this manipulation was as follows. We have hypothesized that when a word is a familiar orthographic pattern, the naming process is not affected by variables such as consistency of spelling-sound correspondences or number of syllables. Hence, disrupting this pattern by presenting the words syllable by syllable should have a negative impact on performance. One might expect, for example, the inconsistent spelling-sound correspondences in the higher frequency exception words to affect performance because they no longer occur as parts of familiar words. On the other hand, if multisyllabic words are decomposed into syllables as part of the naming process, the basic pattern of results obtained in Experiment 2 should replicate when the stimulus display emphasizes these units. Previous research using similar manipulations suggests that lexical decision and naming performance are facilitated when the display emphasizes perceptually salient units. For example, Treiman and Chafetz (1987) have shown that lexical decision latencies for monosyllabic words are facilitated when the stimulus display emphasizes the boundary between onset and rime (e.g., *spl*/ ash); interference results when the display emphasizes other units (e.g., sp/lash). Taft (1987) and Lima and Pollatsek (1983) used a similar methodology to examine the syllable and BOSS units.

#### Experiment 4

### Method

Subjects. Twenty-five McGill University undergraduates were paid \$2 each to participate in the study. All were native speakers of English. None of the subjects had participated in Experiment 2.

*Stimuli*. The stimuli were the same as those used in Experiment 2.

*Procedure.* At the start of each trial, a fixation point (\*) appeared in the center of the screen for 250 ms. The first syllable of a stimulus word then appeared, centered one line above where the fixation point had been and remained for 250 ms. Immediately after the offset of the first syllable, a mask of number signs (###) appeared in its place and the second syllable was displayed centered on the line below where the fixation point had been. In the case of the six pairs of trisyllabic words, the middle syllable was presented with the regular syllable rather than the inconsistent one, and the analogous mode of presentation was used for the trisyllabic control items. The second stimulus display remained on the screen until the subject began to speak into the microphone. The intertrial interval was 2 s.

Subjects were first given 15 practice trials and then 120 experimental trials in two blocks of 60 words each, presented in random order. Subjects were instructed to read each word aloud quickly and accurately as soon as the second part was presented. The experimenter recorded mispronunciation errors by hand.

# Results

The mean reaction times and percentage errors for the four types of exception words and four groups of matched regular words are presented in Table 7. Fifty scores greater than 1,500 ms (1.7% of the trials) were counted as errors; 26 of these slow responses were made by 2 subjects. One percent of scores were excluded from the analyses because of machine malfunctions. As in Experiment 2, there were three factors in the analyses of variance, each with two levels: frequency (high vs. low), regularity (exception vs. regular), and syllable of exception (first vs. last).

Subjects took longer to name low-frequency words (705 ms) than high-frequency words (602 ms),  $F'_{min}(1, 125) = 51.87$ , p < .001, and made more errors on low-frequency words (17.7%) than on high-frequency words (3.5%),  $F'_{min}(1, 139) = 37.38$ , p < .001. Subjects named regular words (627 ms) significantly faster than exception words (680 ms),  $F'_{min}(1, 144) = 18.35$ , p < .001, and made fewer errors on

Table 7Mean Naming Latencies (in Milliseconds) and PercentageErrors, Experiment 4

	High-frequency		Low-frequency	
Word type	M	%	M	%
First syllable		·····		
Exception	637	6.4	769	41.6
Regular	592	2.1	644	5.9
Last syllable				
Exception	601	2.4	713	17.6
Regular	579	2.7	691	5.6

regular words (4.1%) than on exception words (17.1%),  $F'_{\min}(1, 142) = 25.22, p < .001.$ 

There was an interaction between frequency and regularity; the size of the regularity effect was larger for low-frequency words (74 ms) than for high-frequency words (34 ms). This interaction was significant in the analyses by subject, F(1, 24)= 15.57, p < .001, and by item, F(1, 112) = 4.40, p < .05. The 34 ms regularity effect for high-frequency words was significant by subject, t(47) = 4.41, p < .001, and by item, t(112) = 2.47, p < .05. In the error data, the size of the regularity effect was larger for low-frequency words (23.8%) than for high-frequency words (2.3%),  $F'_{min}(1, 141) = 12.77$ , p < .001. The 2.3% regularity effect for high-frequency words was significant by subject, t(47) = 2.22, p < .05, but not by item, t(112) = 1.48, p > .05.

As in Experiment 2, the size of the regularity effect depended on the position of the exception syllable. The regularity effect for high-frequency words was 46 ms when the exception was in the first syllable but 22 ms when the exception was in the last syllable. For low-frequency words, the regularity effect was 125 ms when the exception was in the first syllable and 22 ms when the exception was in the last syllable. Thus, the Frequency × Regularity × Position interaction was significant,  $F'_{min}(1, 138) = 3.94$ , p < .05. The error data were consistent with these results. Note that the high error rate for lower frequency exception words was again due to four items, *viscount, cellist, manger*, and *giblet*.

Figure 1 summarizes the data for Experiments 2 and 4. It can be seen that the method of presentation had different effects on regular and exception words. For exception words, syllabic presentation increased the magnitude of naming latencies for both high- and low-frequency words. Dividing the regular words into syllables, however, had no effect. The net result was an increase in the size of the exception-regular difference in both frequency groups.



Figure 1. Effects of normal (Experiment 2) and syllabified (Experiment 4) stimulus presentation; N = normal; S = syllabified.

# Discussion

The results indicate that the high-frequency words from Experiment 2 produced an exception effect when presented in syllabic units. Thus it was the familiarity of the highfrequency words as patterns that was relevant to performance in Experiment 2. When these patterns were disrupted by manipulating stimulus presentation, effects of inconsistent syllables were obtained. The results of this study can be compared with ones reported by Manelis and Atkinson (1974). In their study, moderate- to high-frequency bisyllabic words were presented tachistoscopically in syllables. In one condition the first syllable was presented, then the whole word appeared, and then the second syllable was presented; in another condition the second syllable was presented, followed by the whole word and then the first syllable. Each unit was displayed for 50 ms and individual syllables were presented in the appropriate spatial position. The proportion of words correctly named was the same in both cases. In a post hoc analysis, Manelis and Atkinson compared accuracy for words with syllables pronounced as they would be in isolation to those with irregularly pronounced syllables. In contrast to the results of Experiment 4, no difference was found. There is an important methodological difference between the studies, however. Manelis and Atkinson used a complex sequence of events on each trial, which included the stimulus word appearing intact. Hence the stimulus presentation conditions did not require subjects to process the words syllable by syllable.

The results of Experiment 4 are consistent with the hypothesis that the pronunciations of higher frequency multisyllabic words are not generated by decomposing the words into syllabic components. When these words were presented as wholes, no effects of inconsistent syllables were obtained. When the words were presented as syllables, inconsistency effects resulted. The results suggest that, as in the case of monosyllabic words, when a multisyllabic word is a familiar orthographic pattern, its pronunciation can be generated with little interference from inconsistencies in spelling-sound correspondences. The results for low-frequency words indicate that inconsistent spelling-sound correspondences influence the naming of these words. These results also indicate, however, that, as in the case of high-frequency words, pronunciations were not generated on a syllable-by-syllable basis. The evidence for this is simply that division into syllables had a negative impact on naming latencies and accuracy for lowfrequency exception words as well. If the low-frequency exception words were named by assigning pronunciations to individual syllables, a stimulus display that emphasized these units would not have interfered with performance. Thus, the increase in naming latencies for the low-frequency exception words suggests that, as in the case of high-frequency words, the process of generating a pronunciation takes into account information provided by the entire letter string, not merely individual syllables. The main effect of presenting the stimuli in syllables is that it eliminated the context relevant to the pronunciation of the initial syllable. Subjects assigned a pronunciation to rig, for example, in the absence of the contextual information that would indicate whether it was pronounced /rig/, as in *rigor* or /rij/, as in *rigid*. This yielded a large inconsistency effect for the initial syllable. Presenting the word's final inconsistent syllable in isolation did not eliminate the prior context, but forced subjects to remember it, producing a smaller inconsistency effect.

This analysis is also consistent with the results for the regular words. As in the case of exception words, the syllabic method of presentation degraded the information relevant to generating a pronunciation. Because the syllables were regular, however, subjects could correctly assign pronunciations syllable by syllable, with little effect because of disruption of the context. The results for the regular words also indicate that the division of words into syllables did not simply make all of the stimuli more difficult to name.

# General Discussion

This series of studies provides evidence concerning some of the processes involved in pronouncing multisyllabic words from print. In Experiment 1, we developed an operational definition of the consistency of spelling-sound correspondences in multisyllabic words, on the basis of earlier research with monosyllabic words. The results indicated that words containing inconsistent syllables, defined in this way, yielded longer naming latencies than words with consistent syllables. Experiment 2 showed that, as in the case of monosyllabic words, the consistency effect was specific to lower frequency words. In Experiment 3, effects of number of syllables on naming were also specific to low-frequency words. Finally, in Experiment 4, presenting the stimuli in syllabic units led to an inconsistency effect for high-frequency words and increased the magnitude of the effect for low-frequency words. The data suggest that the effects of two aspects of word structure-orthographic-phonological regularity and syllabic structure- are related to word frequency. We will now discuss how these results relate to previous accounts of both types of effects, and how the effects relate to each other.

# Spelling-Sound Consistencies

As previously noted, there have been several proposals concerning the representation and use of information concerning spelling-sound correspondences. Traditionally it has been assumed that readers encode knowledge of these correspondences in the form of rules, which are used to generate pronunciations in the naming task. Given the inconsistencies characteristic of written English, the rules will fail to generate the correct pronunciations of a large number of words (e.g., exceptions). These observations (and data principally derived from studies of acquired dyslexia; e.g., Patterson et al., 1985) led to the development of dual-route models of naming, in which there are two processes relevant to naming (Coltheart, 1978, 1987; Forster & Chambers, 1973; Meyer, Schvaneveldt, & Ruddy, 1974). One involves the rules mentioned above. The other involves accessing stored representations of the pronunciations of words. The first process, variously termed the nonlexical, subword, or assembled route, allows pronunciations to be generated and must be used for nonwords. The second process, termed lexical or addressed phonology, in-

volves accessing pronunciations of known words that are stored in a phonological lexicon and must be used for exception words (see Patterson & Coltheart, 1987, for discussion). Higher frequency words show no effects of spelling-sound inconsistencies because they are pronounced through the lexical process; lower frequency words show such effects because readers attempt to assemble their pronunciations using spelling-sound rules. The Seidenberg and McClelland (1989) model takes a different approach to the representation of spelling-sound information. Knowledge of orthographicphonological correspondences is encoded by the weights on connections between processing units in a network structure. By using this type of knowledge representation, naming can be modelled by a single process that takes orthographic input into phonological codes, which are then converted to pronunciations. Naming latencies are determined by characteristics of the computation from orthography to phonology, which are determined by properties of the writing system picked up during learning, particularly the frequency and consistency of spelling-sound correspondences.5

Experiments 1, 2, and 4 showed that the kind of inconsistency relevant to the naming of monosyllabic words also affects the naming of multisyllabic words. Moreover, as in the case of monosyllabic words, inconsistency effects were larger for low-frequency words. The results suggest that the naming of multisyllabic words draws on some of the knowledge representations and processes relevant to monosyllabic words. This outcome probably reflects the fact that the syllables in a multisyllabic word *are* monosyllables. The other important finding from Experiment 1 was that regular inconsistent words produced longer naming latencies than regular words. As noted previously, this type of effect is difficult to explain within dual-route models, which distinguish between rulegoverned items and exceptions but do not acknowledge intermediate levels of inconsistency.

The results of Experiment 4 point to one other important aspect of the naming process: The pronunciations of multisyllabic words are not determined on a syllable-by-syllable basis; rather, pronunciations of syllables are determined by the lexical contexts in which they occur. Experiment 4 showed that presenting words as a sequence of syllables increased the magnitude of inconsistency effects. Thus it is whether rigappears in the context -id or -or that determines whether it is pronounced /rij/ or /rig/; removing or obscuring this context has a negative impact on processing inconsistent syllables. These contextual dependencies could be encoded by the same knowledge structures responsible for effects of simple spelling-sound consistencies. The Seidenberg and McClelland (1989) model is suggestive in this regard because it already incorporates similar kinds of contextual dependencies. For example, when the pattern *-int* occurs in the context of *p*-, the computed pronunciation is /Int/. When it occurs in the context of *m*-, the pronunciation is /int/. The model does not simply encode the fact that int has two pronunciations; it encodes how the pronunciation of this pattern is affected by particular contexts. The contextual dependencies relevant to multisyllabic words are much more complex, of course, and it remains to be determined whether they could be learned through the same principles as simple spelling-sound correspondences and represented in the same type of network structure.

These considerations suggest the following account of inconsistency effects in the naming of multisyllabic words. As in the Seidenberg and McClelland (1989) model, naming involves a computation from orthography to phonology. Weights on connections within a lexical network encode knowledge of spelling-sound correspondences. This knowledge includes a broad range of facts about grapheme-phoneme correspondences, contextual effects, and other phenomena relevant to naming (a much broader range of phenomena than are relevant to monosyllabic words). Perception of the visual stimulus initiates parallel activation processes driven by all letters within the perceptual display. Typically, the number of letters within the perceptual span exceeds the length of a syllable; moreover, most words that are fixated at all are fixated only once (Rayner & Pollatsek, 1987). Given the nature of the input to the system, then, the characteristics of the computation from orthography to phonology will be affected by more than individual syllables. When the input pattern is a familiar one, the computation is relatively "direct," in the sense that it is not affected by inconsistencies in spelling-sound correspondences. Performance on a lower frequency word depends on its consistency vis-à-vis other words.

# Syllables

If this account is correct, it suggests that the naming of multisyllabic words does not involve a preliminary syllabification stage. The question, then, is whether a model lacking any syllabic level of representation of syllabification rules could account for the effects of syllabic structure in studies such as Experiment 3. This question should be considered in light of previous research on syllables and other sublexical units. As we have noted, several models have proposed that complex words are recognized and pronounced by recovering sublexical structures such as syllables. As in the case of spelling-sound correspondences, readers were thought to recover these structures by applying rules. For example, in Spoehr and Smith's (1973) model, syllables were derived by iterative

<sup>&</sup>lt;sup>5</sup> The model also addresses a concern raised by Balota and Chumbley (1985) concerning the locus of frequency effects in naming. Balota and Chumbley distinguished between frequency effects on lexical access and those related to the production of an articulatorymotor response. Having obtained significant frequency effects in a delayed naming paradigm in which subjects had several hundred milliseconds to prepare their responses, they concluded that some frequency effects are due to production, not lexical access. Along the same lines, it could be asked whether the effects we have obtained (concerning frequency, spelling-sound correspondences, and number of syllables) are related to lexical access or production. We consider this issue to be moot, however. McRae, Jared, and Seidenberg (in press) provide data showing that frequency effects in delayed naming are related to the amount of time needed to complete the assembly of a pronunciation. If subjects are provided with sufficient time to assemble pronunciations, no residual frequency effects are obtained. It should also be noted that in a model such as Seidenberg and McClelland's (1989), all effects of frequency on naming are related to production, mainly because there is no lexical access stage.

application of a set of syllabification rules proposed by Hansen and Rodgers (1965). Taft (1979, 1985) proposed heuristics for recovering other sublexical structures such as stem morphemes and BOSSes. Again as in the case of spelling-sound correspondences, English orthography deters this approach because of the inconsistencies with which the relevant units are realized. Whereas minimal pairs such as have-gave and said-paid exhibit the inconsistencies in spelling-sound correspondences, minimal pairs such as naive-waive and provenproved exhibit the analogous inconsistencies in the realization of syllables, and pairs such as decode-deliver or rewriteremain exhibit the inconsistency at the level of morphology. These observations call into question whether sublexical structures can be recovered by rules, whether such a process would be more efficient than a process that did not involve decomposition into component parts, and whether a second route is necessary in order to deal with cases where the rules fail. These questions are underscored by the failure to obtain clear evidence that syllables or other components function as perceptual units (for discussion, see Andrews, 1986; Seidenberg, 1987, 1989).

Several aspects of the present results further call into question the view that word naming involves explicit syllabification. First, the pronunciations of syllables depend on the contexts in which they occur. Second, inconsistencies within syllables had no impact when they occurred in the context of familiar words (Experiment 2). Third, the number of syllables in a word only influenced the processing of low-frequency items (Experiment 3). Fourth, division into syllables did not facilitate naming; instead it exacerbated the effects of inconsistent spelling-sound correspondences (Experiment 4).

It is unclear at this point whether the naming of multisyllabic words requires a preliminary syllabification stage because our studies and others in the literature have not addressed all of the phenomena relevant to pronouncing these words. However, it appears that a minimal model that only encodes correlations between spelling and pronunciation will suffice to account for the syllabic effects in Experiment 3 and many other studies. The reason is simply that the "syllabic" effects in these studies may derive from orthographic and phonological properties correlated with syllables, not syllabification procedures per se. For example, a defining characteristic of the syllable is that it contains a vowel. Although there are inconsistencies in the pronunciations of consonants (e.g., listen vs pasture), vowels are the primary source of spellingsound inconsistencies in English. Hence the effects of number of syllables on naming latency may simply reflect additional processing time associated with computing the pronunciations of each vowel. Thus, the number of syllables in a word would affect the performance of a model that encoded facts about orthographic-phonological correspondences but nothing about syllables at all.

Other types of "syllabic" effects could have a similar derivation. Consider, for example, the finding that syllables tend to act as perceptual groups in tachistoscopic recognition experiments (e.g., Prinzmetal, Treiman, & Rho, 1986). Syllabic structures tend to be reflected in the orthography because syllables are properties of speech and the orthography is alphabetic. The phonotactic properties of speech result in inhomogeneities in the distribution of phonemes and, hence, in the distribution of the letters representing them in the orthography. For example, the letters *gp* cannot occur within syllables because of a phonotactic constraint on the corresponding phonemes; however, the letters can appear at the boundary between syllables, as in *pigpen*. For this and other reasons, the bigrams within a syllable tend to be higher in frequency, on average, than the ones that abut the syllable boundary (see Adams, 1981, for extensive discussion of the orthographic correlates of syllables). Hence, syllables may tend to act as perceptual units because of their orthographic and phonological properties, not because subjects explicitly syllabify words in tachistoscopic recognition (Seidenberg, 1987).

If this logic is correct, it suggests that the effects of spellingsound inconsistencies and number of syllables on naming are similar with respect to the modulating effects of frequency because they derive from a common underlying source. That is, the "syllabic" effects we have observed are actually due to processes involved in resolving spelling-sound ambiguities. This would also account for why studies of syllables and other sublexical units have failed to yield consistent results. Naming does not require the recovery of these sublexical units; their effects will depend on factors such as frequency and their orthographic and phonological properties. For example, there should be larger syllabic effects for words in which the syllables are distinctive in terms of orthography (e.g., *anvil*) than for words in which the syllables are less distinct (e.g., *camel* or *naive*) (Seidenberg, 1987; Prinzmetal et al., 1986).

It remains to be determined whether a model lacking an explicit level of syllabic representation or syllabification rules could account for the entire range of phenomena not addressed by our studies or others in the literature, such as the assignment of syllabic stress. It should be noted, however, that in the Seidenberg and McClelland (1989) model, the computation from orthography to phonology is mediated by an interlevel of hidden units. In a model of this sort, the hidden units pick up higher level generalizations about the correspondence between input and output codes. We speculate that the hidden units will tend to pick up the statistical regularities in terms of the orthographic and phonological characteristics of syllables. Thus, syllable-like units would be an emergent property of the system. We must stress that these observations are merely speculative in the absence of an implemented model. However, a priori considerations concerning the properties of syllables and the properties of models of this type suggest that this approach is worth pursuing further. Moreover, it would obviate the problem of recovering syllabic structures by rule and explain why these units are only relevant to some words.

# Conclusions

In summary, two main points emerge from these studies and from previous work with the monosyllabic words. One is that for a large pool of higher frequency words, variations in terms of lexical structure—orthographic redundancy, consistency of spelling-sound correspondences, and number of syllables—have little impact. Skilled readers are able to identify and pronounce common words with little effect of these properties. The size of the pool of items that are processed in this way appears to be related to level of reading skill (Seidenberg, 1985). A second point is that consistencies in spellingsound correspondences are relevant to the naming of lower frequency mono- and multisyllabic words. These inconsistencies may in turn contribute to the effects of syllabic structure on naming. The studies point to the need for more specific, computational models of the types of knowledge representations and processes relevant to multisyllabic words, possibly building on existing models for monosyllabic words.

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