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Syllable-Internal Structure and the Sonority Hierarchy: Differential Evidence from Lexical Decision, Naming, and Reading

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Treiman (1983) and others have argued that spoken syllables are best characterized not as linear strings of phonemes, but as hierarchically organized units consisting of an onset (initial consonant or consonant cluster) and a rime (the vowel and any following consonants) and that the rime is further divided into a peak or nucleus (the vowel) and a coda (the final consonants). It has also been argued that the sonority (or vowel-likeness) of the consonant closest to the peak, which is a function of its phonetic class, may have an effect on the strength of boundaries determined by the hierarchical division of the syllable (e.g., Treiman, 1984). We examined the evidence for syllable-internal structure and for sonority in two experiments that employed visually presented stimuli and lexical decision, naming, and reading tasks. Our results provide support for the breakdown of the rime into a peak and a coda and for an effect of the sonority of the postvocalic consonant on that break. This pattern occurred only in our lexical decision tasks, so the effect is assumed to be postlexical. We did not find an effect of the onset–rime boundary, perhaps because of an unanticipated effect of word frequency. Our results are discussed in terms of phonological coding in short-term memory.

Recent psycholinguistic evidence has suggested that English syllables are organized hierarchically, divided first into an *onset* (consisting of the

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initial consonant or consonant cluster) and a *rime* (consisting of the following vowel and any additional consonants), with the rime further divided into a *peak* or *nucleus* (consisting of the vowel) and a *coda* (consisting of the remaining consonants).[5] For example, Cooper, Whalen, and Fowler (1986) have shown that the P-center (moment of perceptual occurrence) of a syllable depends on the duration, though not the number, of syllable-initial consonants (the onset). In a later study, they showed the P-center depends to a lesser extent on the rime (Cooper, Whalen & Fowler, 1988). This division of the syllable into an onset and rime is particularly well supported by a number of studies by Treiman (1983, 1986), who taught subjects novel word games in which they were required to recombine components from pairs of nonsense syllables or words, and found that they were more likely to divide those syllables between the onset and rime than elsewhere in order to complete the tasks. More recently, Treiman and Chafetz (1987) have demonstrated evidence for the onset/rime break in *printed* words, using both an anagram and a lexical decision task. In the first case, they found that subjects were better able to recognize a word like *twist* when it was divided TW IST (at the onset/rime boundary) than when it was divided TWI ST (between the peak and the coda). In the second case, subjects responded more quickly in a lexical decision task when the test item contained slashes after the onset (CR//ISP) than after the vowel (CRI//SP).

The evidence in support of dividing the rime into a nucleus and a coda is perhaps somewhat less compelling. Treiman (1983), using novel word games, found only weak support for the nucleus/coda division and suggested that the division might depend on the phonetic makeup of the final consonant cluster. Indeed, when she systematically varied the sonority (or vowel-likeness) of the consonant following the vowel in VCC syllables (Treiman, 1984), she found that subjects in a word game task tended to view liquid consonants, which are quite vowel-like, as belonging to the nucleus or peak; obstruents, which are not at all vowel-like, as belonging to the final consonant cluster or coda; and nasals, which are intermediate in terms of sonority, as showing an equal affinity to both the nucleus and the coda. Derwing, Nearey, and Dow (1987) obtained similar results. These findings are largely in agreement with the proposals of MacKay (1972) and Stemberger (1983) that liquids following the vowel be assigned to the nucleus rather than the coda. The find-

[5] See Selkirk (1982) for theoretical arguments that the syllable is hierarchically organized, but see Davis (1987) for arguments that the syllable is divided, nonhierarchically, into onset, peak, and coda.

ings also agree with the sonority hierarchy proposed for syllables (e.g., Hooper, 1976), which suggests that syllable peaks are peaks of sonority, that consonant classes vary with respect to their degree of sonority, or vowel-likeness, and that segments on either side of the peak show a decrease in sonority with respect to the peak.

However, the evidence connecting the ease of the onset–nucleus break to the sonority of the *prevocalic* consonants has been less consistent. Treiman (1986) found that there was no effect of the phonetic category of the prevocalic consonant on the onset–rime division (suggesting that onsets consisting of more than one consonant remain cohesive), while Derwing et al. (1987) did find such an effect on the phonetic category of the prevocalic consonant.

Most of the evidence for the hierarchical division of the syllable into an onset and rime, and possibly into a nucleus and coda, comes from studies that present stimuli auditorily and require subjects to focus closely on the phonological structure of the stimuli in order to play novel word games or perform segment interchanges. The literature on reading is divided as to whether the phonological code of a visual stimulus is obligatorily accessed (see, e.g., Van Orden, 1990) or whether it is accessed only under certain circumstances (e.g., McCusker, Hillinger, & Bias, 1981). One study that used visual stimuli and looked for evidence of the hierarchical division of the syllable was done by Treiman and Chafetz (1987). As mentioned above, they required subjects to perform either an anagram or a lexical decision task on visually presented stimuli; however, they only compared subjects' responses to stimuli with breaks between the onset and the rime with their response to stimuli with breaks following the nucleus. They did not examine the effects of breaks within initial and final consonant clusters as compared to the two breaks mentioned above, nor did they investigate, in this study, the effect of sonority on the strength of these divisions. As a result of her numerous studies, Treiman (1986) has suggested that the intrasyllabic organization of the syllable should be recognized in theories of speech perception and production as well as in theories of reading.

Research that has compared the results of lexical decision and word-naming tasks (e.g., Seidenberg, Waters, Sanders, & Langer, 1984) suggests that certain effects may be postlexical, i.e., a result of processing that occurs after lexical access. Thus, such effects emerge only in lexical decision and not in naming tasks, since naming typically takes less time and is thus believed to involve less postlexical processing. It is often assumed, however, that naming a visually presented word requires accessing its phonological code (e.g., Seidenberg, 1985). Silent reading of visually presented stimuli is another task that has been shown to be sensitive to semantic and phonological priming (McNamara & Healy, 1988), while also presumably requiring less postlexical processing. It would be of interest, therefore, to see whether evidence for the hierarchical structure of the syllable can be found in each of these three tasks.

The present experiments are thus designed (a) to replicate Treiman's (1984) finding that the break between the nucleus and coda varies as a function of the phonetic class (liquid, nasal, or obstruent) of the postvocalic consonant, with postvocalic liquids showing the greatest cohesion to the nucleus and obstruents showing the least, (b) to test for a similar effect of the phonetic class of the prevocalic consonant on the break between the onset and the rime, and (c) to determine whether any evidence for such breaks is pre- or postlexical in origin by comparing the results of lexical decision tests with those of naming and reading.

EXPERIMENT 1

Subjects responded orally to visually presented stimuli, including both words and nonwords, all of which were monosyllabic and five letters long. Each visually presented stimulus could be interrupted at one of six possible locations by an asterisk. One group of subjects performed a lexical decision task while a second group named each of the items out loud.

Method

Stimuli. Two sets of test items were constructed, one to examine the effect of the composition of initial consonant clusters on the cohesion of the onset–rime boundary of the syllable and another to examine the effect of the composition of final clusters on the cohesion of the rime-internal nucleus–coda boundary. All test items were single syllables, contained five letters, and, with the exception of some of the onset–rime test items, described below, all had a $C_1C_2VC_3C_4$ phonemic structure.

In the case of the onset–rime test words, C_2 was either a liquid (12 items), a nasal (6 items), or an obstruent (6 items).[6] There were 12 additional five-letter words with no initial consonant cluster, but with an initial single phoneme, e.g. /ʃ/, which is normally represented by two

[6] Four of the six nasal items and one of the six obstruent items had a $C_1C_2VC_3$ structure, although all were five letters long.

letters, "sh."[7] Nine of these items had a $C_1VC_2C_3$ phonemic structure, and three had a C_1VC_2 structure. All were five letters long. All words were also low frequency, with the mean frequency for the liquid items 7.3 (Kučera & Francis, 1967), for nasal items 9.8, for obstruent items 6.8, and for single-phoneme items 7.8. The corresponding onset–rime nonword test items were constructed by switching the vowel and final consonants of one item with the vowel and final consonants of another item from the same series, so that two nonwords were created (e.g., *craft* and *flint* giving *crint* and *flaft*).

In the case of the nucleus–coda test words, there were 12 words each for which C_3 was a liquid, a nasal, or an obstruent. The corresponding nucleus–coda nonword test items were constructed as above (e.g., *blunt* and *swamp* yielding *swunt* and *blamp*). The mean frequency for the liquid items was 9.8, for the nasal items 9.1, and for the obstruent items 9.8.

Each word and nonword (see the appendix for the complete list) could appear with an asterisk in one of three positions. For the onset–rime test items, the asterisk could appear before the word (position 1), after the first letter (position 2), or between the second letter and the vowel (position 3), e.g., *CRAFT, C*RAFT or CR*AFT. For the nucleus–coda test items, the asterisk could appear after the vowel (position 4), after the third consonant (position 5), or after the word (position 6), e.g., BLU*NT, BLUN*T, BLUNT*. Positions 1 and 6 are control positions because the asterisk does not interrupt either the initial or the final consonant cluster.

Three lists of 144 test items were prepared. Each word and nonword appeared only once on each list.[8] The order of presentation was pseudorandom with the following constraints: In every 12 items there was an equal number of onset–rime and nucleus–coda test words and nonwords and an equal number of asterisks at each of the six positions. For the nucleus–coda test items, in every group of 12, there were two stimuli with a liquid, nasal, or obstruent as the C_3 phoneme. For the onset–rime items, in the same group of 12, there were two stimuli with a liquid as the C_2 phoneme, two stimuli with a single initial consonant, and either two stimuli with a nasal as the C_2 phoneme or two stimuli with an

[7] Three of the items in this group began with the letters "ch," characterized by some phonologists as a single phoneme /č/ and by others as a sequence of two phonemes /tʃ/.

[8] We inadvertently included two items that appeared both as onset–rime and as nucleus–coda test items, *stern* and *brand*. The associated nonwords were different in each case.

obstruent as the C_2 stimuli. The three lists differed only as to the location of the asterisks, with each one of three possible asterisk locations occurring once across lists for every stimulus.

Procedure. Subjects were told that strings of letters would appear on the computer screen in front of them. Subjects in the lexical decision condition were to say *yes* if the string was a word and *no* if it was not. Subjects in the naming condition were to read the word or nonword out loud. A voice key was used to record subjects' response times. The experimenter first made sure that the key was responding properly to the level of the subject's voice, and the subject was instructed not to make inadvertent noises, as the key was quite sensitive. Subjects' responses were recorded on cassette tapes. The experimenter noted all errors in both conditions, so that the responses to those items would be excluded from analysis.

Subjects. Twenty-four Wellesley College undergraduates were paid for their participation in the experiment and were assigned to conditions by order of arrival, according to a fixed rotation.

Results

The onset–rime and nucleus–coda words represented different sets of words[9] and therefore each set of items was analyzed separately. All response latencies were reciprocally converted to speeds for the analyses,[10] but the resulting mean speeds were converted back to latencies for reporting in the text and in the figures. Two sets of analyses were performed, one on the latencies for correct responses and another on the error proportions. A response was considered an error in the naming task if a subject failed to respond or if the response was incorrect. Items were not treated as a random effect because the stimuli were not randomly selected (Wike & Church, 1976).

We need to obtain an effect of asterisk position in order to demonstrate syllable-internal structure and an interaction of asterisk position with cluster composition in order to demonstrate an effect of the sonority hierarchy on syllable-internal cohesiveness.

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[9] We do not report the results of our analysis of the nonword data because the significant effects provided no support for syllable-internal structure or sonority and were inconsistent across the two experiments. A comparison of the speed analysis and the error analysis also indicated a number of probable speed–accuracy tradeoffs, although these were not evident in the word data.

[10] This transformation produced more normally distributed values and eliminated disproportionate influences by outliers.

Onset–Rime Words. For the onset–rime test words, the analyses included one between-subjects factor, response condition (lexical decision or naming), and two within-subjects factors, onset composition (C_2 either an obstruent, liquid, nasal, or the second grapheme of a single phoneme) and asterisk position [immediately preceding the word (position 1) or following the first (position 2) or second (position 3) letter]. In these analyses we did not find the anticipated asterisk position effect nor the anticipated asterisk position by onset composition interaction. However, we did find some interesting effects of response condition and onset composition.

As would be expected if, indeed, the lexical decision task requires additional postlexical processing, the mean latency for naming (673 msec) was faster than that for lexical decision (831 msec). Likewise, the error proportions were higher for lexical decision (.092) than for naming (.042). In the overall analysis of response latency for onset–rime words, there was a significant main effect of response condition (lexical decision vs. naming), $F(1, 22) = 12.37, p = .0022, MSe = 5.7176$. The effect of response condition was also significant in the error analysis, $F(1, 22) = 8.36, p = .0083, MSe = 0.1824$.

Although the differences in frequency were small among the words comprising the different onset composition groups, the differences in frequency seem to have produced corresponding differences in both mean latencies and error proportions. Recall that the mean frequency for nasals was 9.8, for one-phoneme items 7.8, for liquids 7.3, and for obstruents 6.8. Correspondingly, the mean latencies for nasal test items (722 msec), one-phoneme items (729 msec), liquids (734 msec), and obstruents (796 msec) increased as the items became less frequency, as did the error proportions, with one small reversal (nasal = .028, one-phoneme = .067, liquid = .061, obstruent = .111). In the latency analysis, there was a significant main effect of onset composition, $F(3, 66) = 6.26, p = .0011, MSe = 0.2513$, which was also significant in the error analysis, $F(3, 66) = 4.33, p = .0077, MSe = 0.0844$.

The effect of onset composition, which presumably reflected the frequency of the words for each of the onset composition types, was evident for the lexical decision task but not for the naming task. As was the case for the combined data, for the data from the lexical decision task, latencies increased as word frequency declined, and error proportions also increased, with one small reversal. The latencies and error proportions in the lexical decision task were 766 msec and .042 for nasals, 808 msec and .093 for one phoneme, 844 msec and .081 for liquids, and 923 msec and .153 for obstruents. There was a significant

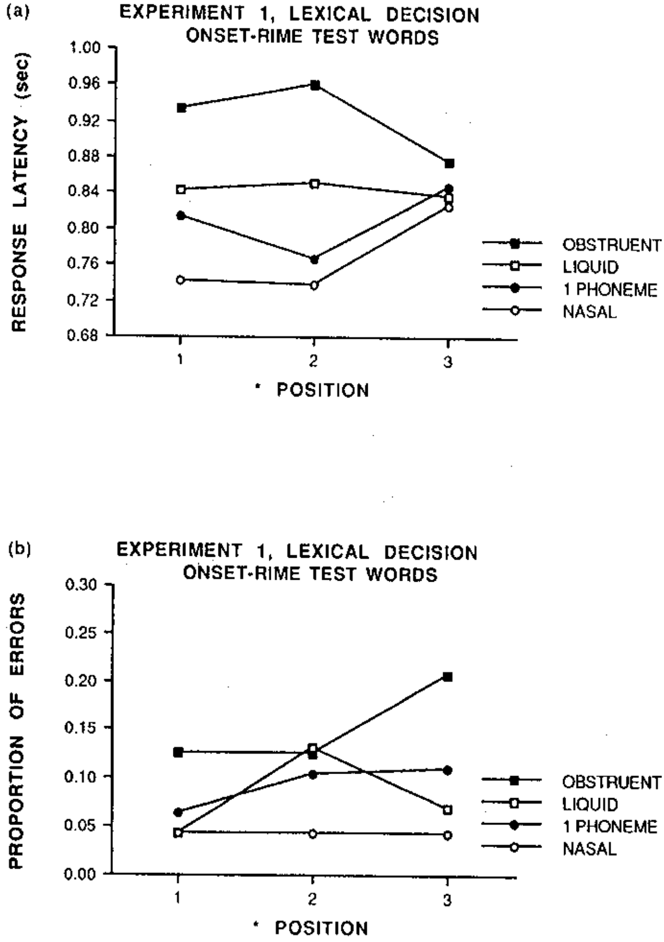


Fig. 1. The results of the onset–rime test words in Experiment 1 as a function of the phonetic class of C_2 and of asterisk position. The asterisk appears before the word at position 1, after the first letter at position 2, and between the first and second letter at position 3. Panels (a) and (b) are for the lexical decision task; panels (c) and (d) are for the naming task. The latency analysis is shown in panels (a) and (c); the error analysis is shown in panels (b) and (d).

interaction of onset composition with response condition, $F(3, 66) = 3.61$, $p = .0174$, $MSe = 0.1449$, in the latency analysis, but not in the error analysis. In a separate planned analysis of the lexical decision

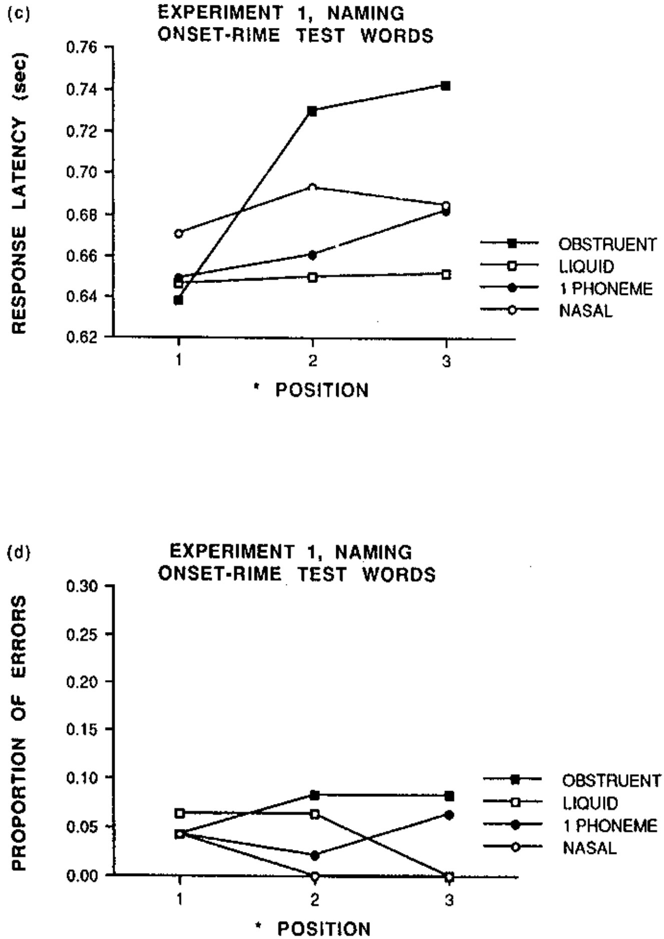
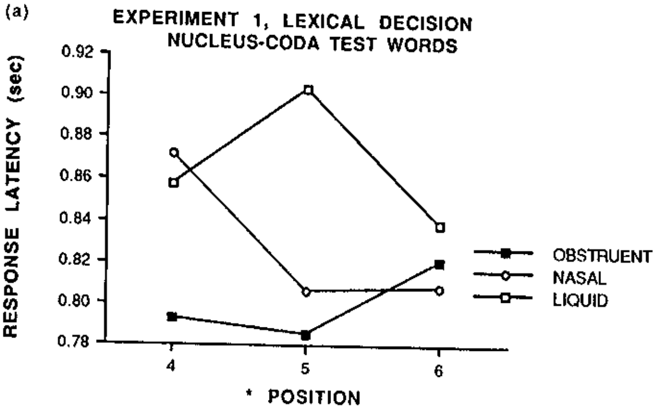


Fig. 1. Continued.

latencies, done to investigate the source of this interaction, there was a significant effect of onset composition, $F(3, 33) = 6.85, p = .0013$, $MSe = 0.3114$, which was marginally significant as well in an error analysis of the lexical decision task, $F(3, 33) = 2.57, p = .0699, MSe = 0.0762$. There were no significant effects in either the latency or the error analysis of the naming data, so this pattern seems limited to the lexical decision data (see Fig. 1).

Nucleus–Coda Words. For the nucleus–coda test words, the analyses



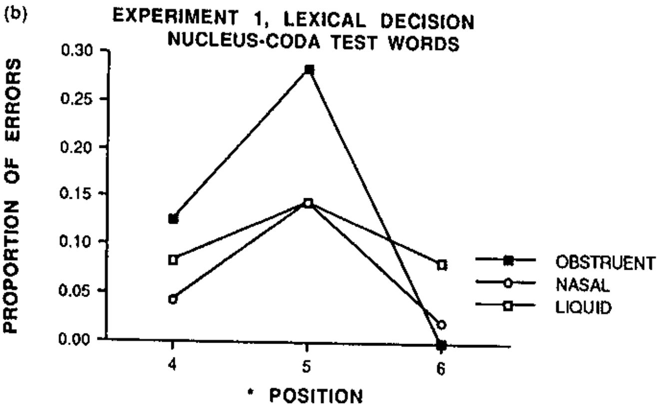


Fig. 2. The results of the nucleus–coda test words in Experiment 1 as a function of the phonetic class of C_3 and of asterisk position. The asterisk appears after the vowel at position 4, between the last two letters at position 5, and after the word at position 6. Panels (a) and (b) are for the lexical decision task; panels (c) and (d) are for the naming task. The latency analysis is shown in panels (a) and (c); the error analysis is shown in panels (b) and (d).

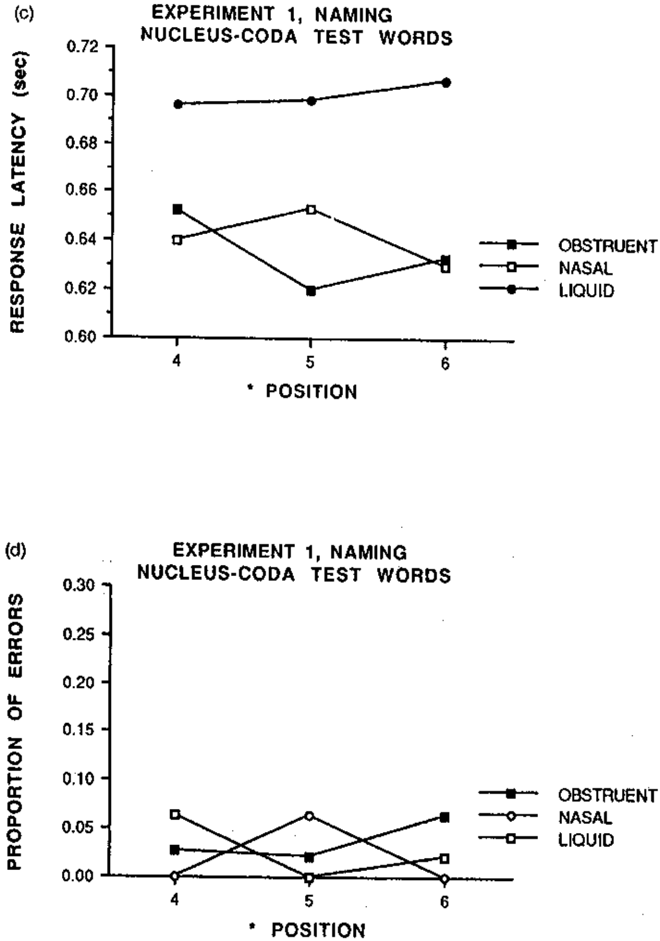


Fig. 2. Continued.

included one between-subjects factor, response condition (lexical decision or naming), and two within-subjects factors, coda composition (C_3 either an obstruent, liquid, or nasal) and asterisk position [immediately following the vowel (position 4) or following C_3 (position 5) or C_4 (position 6)].

As found for the onset–rime words and as expected under the assumption that the lexical decision task requires more (postlexical) processing than does the naming task, the mean latency for lexical decision (830 msec) was longer than for naming (657 msec). Likewise, the mean error proportion for lexical decision was higher (.103) than for naming (.029). In the analysis of the nucleus–coda test items, there was a significant effect of response condition, lexical decision vs. naming, $F(1, 22) = 15.26$, $p = .0010$, $MSe = 5.3887$. This effect was also significant in the overall error analysis, $F(1, 22) = 22.78$, $p = .0002$, $MSe = 0.3025$.

Just as there was an effect of onset composition for the onset–rime words, there was an effect of coda composition for the nucleus–coda words. However, the effect in this case was only evident for latencies, not errors, and did not reflect differences in word frequency, which were minimal. The overall latency (combining data from the lexical decision and naming tasks) to C_3 obstruents (708 msec) was shorter than to nasals (723 msec), which were in turn shorter than to liquids (775 msec). (See Fig. 2.) There was a significant main effect in the latency data of the coda composition, $F(2, 44) = 16.66$, $p < .0001$, $MSe = 0.2914$, not significant in the error analysis.

None of the remaining effects in the latency analysis were significant. Most crucially, there was no effect of asterisk position or interaction of asterisk position and coda composition. There were, however, several other interesting effects in the error analysis, and the expected effect of asterisk position and the expected interaction of asterisk position and coda composition were evident for the lexical decision task, but not for the naming task. (See Fig. 2.) Overall error proportions in position 5 (.110) were higher than in position 4 (.057) or in position 6 (.031). Whereas the most errors occurred in position 5 overall and for all coda compositions with the lexical decision data, with the naming data the most errors occurred in position 6 for the obstruents, in position 5 for the nasals, and in position 4 for the liquids. (See Fig. 2.) The main effect of asterisk position was significant in the error analysis, $F(2, 44) = 10.42$, $p = .0004$, $MSe = 0.1161$. There was also an asterisk position by response condition interaction, $F(2, 44) = 10.57$, $p = .0004$, $MSe = 0.1178$, and a three-way interaction of asterisk position by response condition by coda composition, $F(4, 88) = 2.92$, $p = .0253$, $MSe = 0.0362$.

As with the onset–rime words, planned analyses were conducted on the data with the nucleus–coda words separately for the lexical decision and naming tasks. For the lexical decision latencies, as for the combined latencies, there was an effect of coda composition, with latencies to items in which C_3 was an obstruent shorter (799 msec) than those in which C_3 was a nasal (828 msec), which were in turn shorter than those in which C_3 was a liquid (866 msec). There was a significant main effect of coda composition in the analysis of the lexical decision latencies, $F(2, 22) = 5.44, p = .0120, MSe = 0.0841$.

For the lexical decision errors, as for the combined errors, there was an effect of asterisk position, with the most errors (.19) occurring when the asterisk appeared between C_3 and C_4 in position 5, next most (.08) when the asterisk appeared between the vowel and C_3 in position 4, and fewest (.04) when the asterisk appeared at the end of the word in position 6. However, as anticipated, the effect of asterisk position depended on coda composition to some extent. As can be seen in Fig. 2, obstruents and, to a lesser extent, nasals showed a dramatic increase in the proportion of errors when the asterisk intervened at position 5 between C_3 and C_4, but the increase in errors for liquid items with an asterisk at position 5 was less pronounced. There was a significant main effect of asterisk position in the error analysis of the lexical decision task, $F(2, 22) = 14.50, p = .0002, MSe = 0.2339$. There was also a marginally significant interaction of asterisk position and coda composition, $F(4, 44) = 2.44, p = .0601, MSe = 0.0400$.

For the naming latencies, as for the lexical decision latencies and the combined latencies, responses to items with C_3 as an obstruent were shorter (635 msec) than to those with a nasal (641 msec), which in turn were shorter than to those with a liquid (700 msec). The main effect of coda composition was significant, $F(2, 22) = 12.06, p = .0004, MSe = 0.2355$, and there were no other significant effects in the analysis of naming latencies. There were no significant effects at all in the error analysis of the naming data.

Discussion

Our analysis of the words designed to test the cohesiveness of the onset–rime boundary and the possible effect of the sonority hierarchy on that boundary produced some surprising results. There were no effects of syllable-internal structure or sonority in the naming data. The lexical decision data also failed to demonstrate any such effects, but showed an apparent effect of word frequency, in both the latency and error analyses.

The analysis of the nucleus–coda test items proved somewhat more promising with respect to syllable structure and sonority (see also Treiman, 1984, 1986). In the overall error analysis, there were significantly more errors when the asterisk intervened at position 5 (between the two consonants of the coda) than at position 4 (immediately after the vowel) or at position 6 (at the end of the word). These results suggest that interruption at the nucleus–coda boundary (after the vowel) is less disruptive than within the coda itself. In both the separate lexical decision and naming latency analyses there were significant main effects of coda composition, with responses to obstruent items faster than to those with a nasal, which in turn were faster than to those with a liquid. Indeed, this was the only significant effect found in the separate analysis of the naming data. On the other hand, in the error analysis of the lexical decision data, there was a significant effect of asterisk position, showing that the disruptive effect of the asterisk appearing within the coda is a postlexical effect. Finally, there was also a marginally significant interaction for the lexical decision error analysis of the coda composition with asterisk position. This interaction provided partial support for the notion that the class of the *postvocalic* consonant affects the cohesiveness of the nucleus and the coda. Postvocalic obstruents are lowest on the sonority hierarchy. Thus, they are expected to show the *least* cohesiveness with the preceding vowel and the *most* cohesiveness with the final consonant, followed by nasals and then liquids. As Fig. 2 illustrates, errors were greatest for test items with an obstruent when the asterisk interrupted the rime at position 5. Nasal test items showed a similar disruption in that position. On the other hand, liquid test items should have shown more errors with an asterisk in position 4, rather than an increase at position 5, because of the greater cohesiveness of liquids to the precedeing vowel. However, that was not the case.

Because of the constraints we followed in constructing the stimuli for this experiment, it was not possible to have all test items begin with the same sound, which would have been ideal since we used a voice key to record subjects' responses. We wondered whether the various phonetic identities of the first consonants of our test items had had an effect on the naming speeds. We also wondered whether our use of the voice key to record subjects' responses in the lexical decision task had introduced greater variability in the response times than would have been the case with a reaction time key (see, e.g., Pechmann, Reetz, & Zerbst, 1989). If so, it might explain why our evidence for syllable-internal structure and for some influence of the sonority hierarchy on the nucleus-coda boundary only emerged in the error analysis. We decided to repeat the experiment using a manual reaction time key and substituting a silent reading task for our naming task.

EXPERIMENT 2

In this experiment, we compared the responses of one group of subjects in a lexical decision task to those of another group of subjects whose task was to read the word and nonword stimuli silently and to press a key as soon as they were done with each item. McNamara and Healy (1988) have demonstrated semantic and rhyme facilitation with a self-paced reading task of this type, which, however, like naming, is assumed to involve less postlexical processing than lexical decision.

Method

Stimuli. The same stimuli used in Experiment 1 were used in Experiment 2.

Procedure. The procedure was essentially the same as in Experiment 1, except that a reaction time key was used instead of a voice key. Subjects in the reading condition were to read the word or nonword silently and to press a button with the index finger of their right hands as soon as they had finished reading each item. Subjects in the lexical decision condition were to decide whether or not each letter string was an English word. They were told to rest the index finger of their right hand on the *yes* button and the index finger of their left hand on the *no* button, and to press *yes* as quickly as possible if the string was a word, and *no* as quickly as possible if the string was not a word. They were told that both speed and accuracy would be scored by the computer.

Subjects. Thirty-six male and female undergraduate students from the University of Colorado at Boulder participated in this experiment. They received course credit for their participation. They were assigned to conditions by order of arrival, according to a fixed rotation.

Results

As in Experiment 1, the onset–rime and nucleus–coda test words were analyzed separately. Two sets of analyses were performed, one on error rates (for the lexical decision data only) and another on the latencies for correct responses. All response latencies were reciprocally transformed to speeds for the analyses, but the resulting mean speeds were converted back to latencies for reporting in the text and in the figures, as for Experiment 1. Also as for Experiment 1, items were not treated as a random effect because the stimuli were not randomly selected (Wike & Church, 1976).

Onset–Rime Words. As in Experiment 1 and as anticipated given that the lexical decision task presumably requires additional postlexical processes not included in the reading task, the mean latency for reading (758 msec) was considerably shorter than that for lexical decision (920

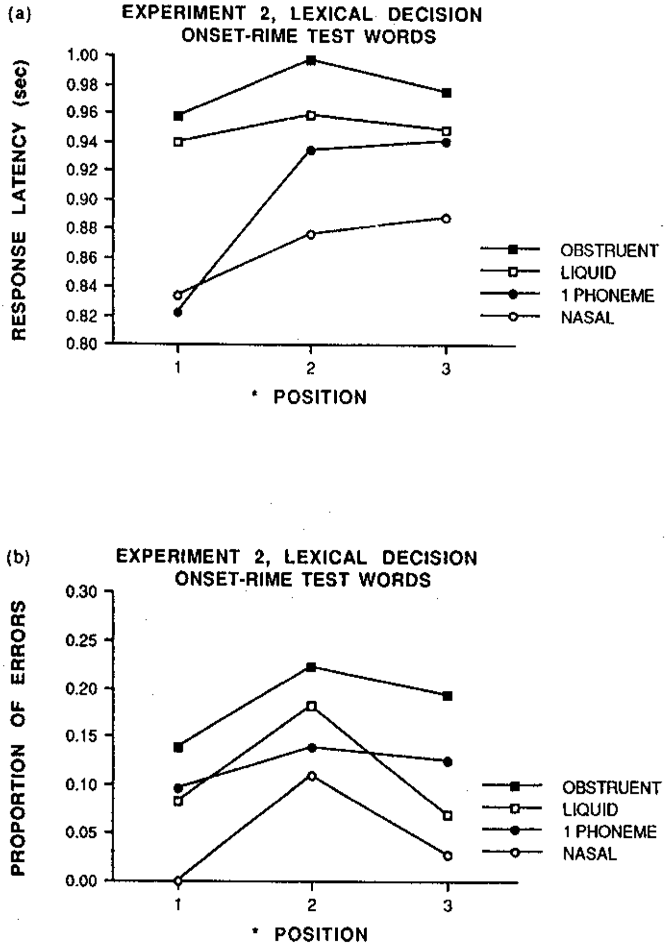


Fig. 3. The results of the onset–rime test words in Experiment 2 as a function of the phonetic class of C_2 and of asterisk position. The asterisk appears before the word at position 1, after the first letter at position 2, and between the first and second letter at position 3. Panels (a) and (b) are for the lexical decision task; panel (c) is for the reading task. The latency analysis is shown in panels (a) and (c); the error analysis is shown in panel (b).

msec). In the overall latency analysis of the onset–rime test items there was a significant main effect of lexical decision vs. reading, $F(1, 34) = 4.56, p = .0378, MSe = 5.8280$. Also in accord with predictions, based

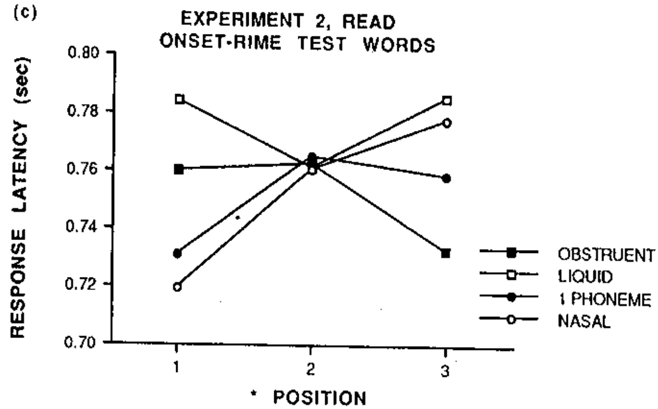
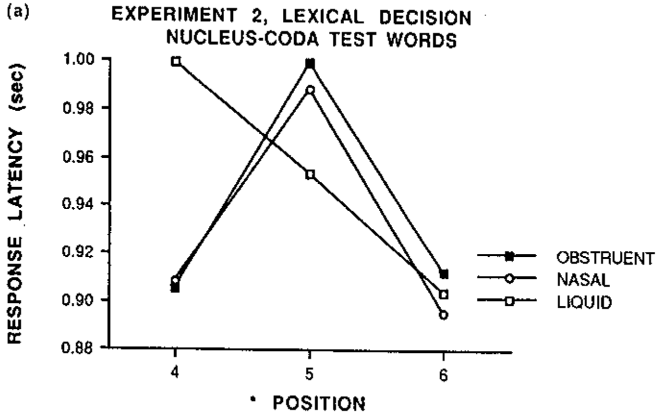


Fig. 3. Continued.

on the assumption that the asterisk should be least disruptive when it precedes the word, the response latency for stimuli with immediately preceding asterisks (position 1) was shorter than for stimuli with asterisks in positions 2 and 3 (1.234 vs. 1.188 and 1.189, respectively). There was a significant main effect for asterisk position, $F(2, 68) = 4.44$, $p = .0152$, $MSe = 0.0999$.

Also as in Experiment 1, despite the small differences in frequency among the words comprising the different onset composition groups, the average latency for each onset composition varied largely as a function of the frequency of the words in the four groups, with more frequent words producing shorter latencies. Thus, latency of response (805 msec) was shortest to nasal test items (mean frequency 9.8), followed by the latency of response (817 msec) to single-phoneme test items (mean frequency 7.8), followed by a minor reversal, with response latency (855 msec) to liquid test items (mean frequency 7.3) slightly slower than average latency (850 msec) to obstruent test items (mean frequency 6.8). There was a main effect of onset composition, $F(3, 102) = 8.43$, $p = .0001$, $MSe = 0.1338$, as well as a significant interaction of onset composition with lexical decision vs. reading, $F(3, 102) = 5.21$, $p = .0026$, $MSe = 0.0826$.

Separate planned analyses of the reading and lexical decision onset–rime word data were conducted to explore the source of the interaction. In Experiment 1 the correlation of word frequency and onset composition class was evident for the lexical decision task but not for the naming



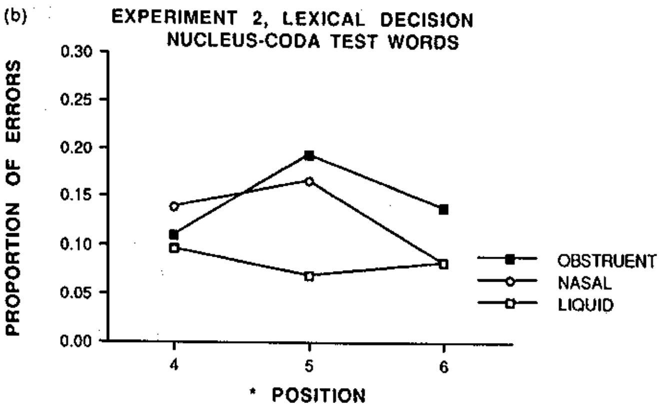


Fig. 4. The results of the nucleus–coda test words in Experiment 2 as a function of the phonetic class of C_3 and of asterisk position. The asterisk appears after the vowel at position 4, between the last two letters at position 5, and after the word at position 6. Panels (a) and (b) are for the lexical decision task; panel (c) is for the reading task. The latency analysis is shown in panels (a) and (c); the error analysis is shown in panel (b).

task. Similarly, the correlation of word frequency and onset composition class in the present experiment occurred in the lexical decision task but not in the reading task. There was an effect of onset composition on reading, but this effect was clearly due to the difference between those

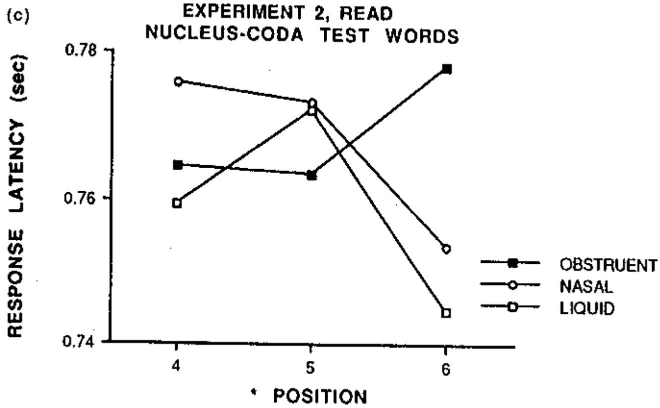


Fig. 4. Continued.

words in which C_2 was a liquid (777 msec) and all the others (obstruent = 751 msec, one phoneme = 751 msec, and nasal = 752 msec). In the separate reading analysis, there was a significant effect of onset composition, $F(3, 51) = 3.40, p = .0241, MSe = 0.0254$. There were no other significant effects in the reading analysis.

The latency data from the lexical decision task alone mirror the combined data from both tasks. As in the overall data, latencies in the lexical decision task to words where the asterisk appeared at the beginning were faster (884 msec) than those to words where the asterisk appeared after the initial consonant (940 msec) or just before the vowel (937 msec), as expected because the asterisk should be more disruptive when it occurs in the middle of a word than when it precedes the word. The effect of asterisk position was marginally significant in the lexical decision latency analysis, $F(2, 34) = 3.16, p = .0538, MSe = 0.1022$.

As can be seen in Fig. 3, both the pattern of errors (which were analyzed for the lexical decision task only, because no errors were possible in the reading task) and the pattern of response latencies for the lexical decision task varied as a function of the frequency of the four groups of words, with error proportions (with the exception of one small reversal) lower for more frequent items, and with latencies shorter for the more frequent items, as in Experiment 1. The mean latencies, given in terms of nasal, single-phoneme, liquid, and obstruent test items (that is, in order from most to least frequent), were 866, 895, 949, and 977 msec, whereas the error proportions (in the same order) were .046, .120, .111, and .185. There was a significant effect of onset composition for both the latencies, $F(3, 51) = 7.87$, $p = .0004$, $MSe = 0.1910$, and the error proportions, $F(3, 51) = 5.31$, $p = .0032$, $MSe = 0.1740$.

Nucleus–Coda Words. As found in Experiment 1 and for the onset–rime words in the present experiment and as expected under the assumption that the lexical decision task requires more postlexical processing than does the reading task, the mean overall latency for reading nucleus coda words (765) was considerably shorter than that for lexical decisions on those words (939). For the combined analysis of the nucleus–coda test word latencies, there was a significant main effect of lexical decision vs. reading, $F(1, 34) = 5.14$, $p = .0281$, $MSe = 4.751$.

Just as we predicted and found that asterisks were less disruptive when they preceded a word than when they occurred in the middle of a word for the onset–rime stimuli, the asterisks should be less disruptive when they follow a word than when they occur in the middle of a word for the nucleus–coda stimuli. Indeed, the latency for words with item-final position 6 asterisks (825) were shorter than those for position 4 asterisks (842), which were in turn shorter than those for position 5 asterisks (862). There was a significant main effect of asterisk position in the combined analysis of the nucleus–coda test word latencies, $F(2, 68) = 5.30$, $p = .0074$, $MSe = 0.0730$.

Most crucial is the predicted interaction of coda composition and asterisk position. The predicted pattern was found for the lexical decision latencies, but not for the errors in the lexical decision task nor for the latencies in the reading task. As anticipated, the obstruents and nasals showed longer lexical decision latencies at position 5, whereas the liquids showed the longest lexical decision latencies at position 4. (See Fig. 4.) In a separate planned analysis of the lexical decision latencies, there was, in addition to a significant main effect of asterisk position, $F(2, 34) = 5.7$, $p = .0075$, $MSe = 0.0990$, a marginally significant interaction of coda composition and asterisk position, $F(4, 68) = 2.44$, $p = .0543$, $MSe = 0.0335$. It should be noted that, although this crucial interaction was only marginally significant by this test, the statistic used was very conservative because it was not directional. If a directional test were employed (which seems appropriate in this case because a specific pattern of results was anticipated and obtained), then the results would be clearly significant. In any event, there were no significant effects in the separate analysis of mean proportion errors for lexical decision nor in the separate analysis of the latencies for the reading data.

Discussion

As in Experiment 1, we found highly consistent significant differences between our two tasks in both the latency and error analyses. These significant effects are, of course, consistent with the notion that the lexical decision task requires additional processing.

When we consider the onset–rime data, the most interesting effect that emerged is the effect of onset composition, such that speeds and error rates varied largely as a function of the frequency of the stimuli in each of the onset-composition groups. As in Experiment 1, both the separate latency and error analyses of the lexical decision data showed that responses to the different onset-composition groups varied as a function of their frequency. On the other hand, the main effect of onset composition in the separate latency analysis of the reading data was due to slower response times to stimuli with liquids as the second consonant. There was also an effect of asterisk position in the lexical decision latency analysis, but it provided no support for the internal structure of the syllable, because there was no difference in the latencies to words with asterisks appearing within the onset as compared to those with asterisks between the onset and the vowel. But the response latencies in both of those positions were marginally significantly slower than when the asterisk appeared at the very beginning of the word.

As in Experiment 1, it was only the analysis of the nucleus–coda data that provided some support for the notion of syllable-internal structure and for the influence of the sonority hierarchy on that structure. Thus, asterisks placed between the nucleus and the coda were less disruptive than those placed within the coda, for the lexical decision analysis. More importantly, in the separate latency analysis of the lexical decision data, there was an interaction (which was marginally significant by a conservative nondirectional test) between asterisk position and coda composition, so that test items with postvocalic liquid consonants produced the slowest latency of response when the asterisk appeared immediately after the vowel in position 4, whereas test items with postvocalic nasals and stops produced the slowest speeds of response when the asterisk appeared just before the final consonant in position 5. This pattern is consistent with an effect of the sonority hierarchy on the nucleus–coda boundary, because liquids are higher on the sonority hierarchy and therefore more cohesive with the preceding vowel (hence the slower latency for asterisks in position 4), whereas obstruents and nasals are lower on the sonority hierarchy and therefore more cohesive with the following consonant (hence the slower speeds for asterisks in position 5).

GENERAL DISCUSSION

We found evidence, but only in our lexical decision tasks, in support of the division of the rime into a nucleus and a coda as well as evidence that suggests that the sonority of the postvocalic consonant affects the strength of that break. It appears from our data that these syllable-structure effects are postlexical (occurring in the lexical decision rather than in the naming or reading tasks).

On the other hand, despite the wealth of psycholinguistic evidence supporting the syllable-internal structures of onset and rime, we were unable to find evidence to support this division in our two experiments. Instead, we found evidence of a word-frequency effect, even though we controlled for word frequency,[11] such that the differences among the word frequencies in the four onset groups were not significant. This unanticipated word-frequency finding has potential methodological import. Given multiple experimental constraints, researchers have probably been unable in many cases to find exact frequency matches for their stimuli. They have probably generally assumed that small frequency differences of the type that separated our groups of onset–rime words would be unlikely to produce any effect. Furthermore, the finding also has theoretical import, since these small frequency differences turn out, at least in this case, to matter significantly. Indeed, our word-frequency effect was strong enough, occurring in both experiments and for both accuracy and latencies, to override any effect of the onset–rime break.

We would suggest that previous studies that supported the notion of a break between the onset and rime, even with nonword stimuli, were able to find such evidence because the tasks that they employed relied largely on a form of phonological coding used to maintain information

[11] Although there were differences in frequency in the onset–rime groups, these differences were not significant, $F(3, 32) = .162, p = .9208, MSe = 69.8620$. Nonetheless, we believe that the onset effect is best explained in terms of word frequency. We examined single-letter and di- and trigram frequencies (Mayzner & Tresselt, 1965; Mayzner, Tresselt, & Wolin, 1965) and found no correlation with the pattern of our results for onset–rime (or coda) test words. Furthermore, both the word and the nonword stimuli had the same initial consonant clusters, but the onset effect only occurred in the word data. Finally, as suggested by an anonymous reviewer, we compared the mean latencies of the subjects in our two experiments to s + n onset–rime words (which are relatively infrequent) and s + m onset–rime words (which are relatively frequent) and found a significant frequency effect there as well, $t(29) = 3.188, p = .0034$, two-tailed.

in short-term memory, a form of phonological coding which may not be required by simple naming and reading tasks.

Besner and Davelaar (1982) presented evidence that the phonological code used to achieve lexical access from print is *not* the same phonological code used to maintain information in short-term memory. In particular, they found that subjects better recalled nonwords with an entry in the phonological lexicon (e.g., BRANE) than nonwords without such an entry (e.g., SLINT) even under conditions of articulatory suppression, whereas effects of phonological similarity and word length were eliminated by articulatory suppression. Because of the opposing effects of articulatory suppression, they argue that there are two phonologial codes. The first phonological code permits lexical access, whereas the second code, more strongly affected by articulatory suppression, is used to maintain information in short-term memory. If we assume that the first phonological code not only permits lexical access but also subserves naming and that effects of syllable structure and sonority emerge through use of the second, short-term-memory phonological code, then we can reconcile our results with those of previous studies.

The majority of the psycholinguistic studies finding evidence in support of the hierarchical structure of the syllable involve tasks that require the maintenance of information in short-term memory. The novel word games task used frequently by Treiman (1983, 1984, 1986) and the substitution-by-analogy task (where subjects switch specified parts of two jointly presented monosyllabic strings) used by Derwing et al. (1987), Dow (1987), Fowler (1987), and others involve such a demand. Thus, it is reasonable to assume that they required use of the phonological code that maintains information in short-term memory and from which effects of syllable structure and sonority emerge. Indeed, Treiman and Danis (1988) demonstrated syllable structure effects using a short-term memory task.

Perhaps lexical decision, unlike naming and reading, makes a greater demand on short-term memory. For example, subjects in a lexical decision task may store accessed items in short-term memory for decision processing. Our consistently significant differences between lexical decision, on the one hand, and naming and reading on the other, support, as do many other studies, the notion of additional postlexical processing in lexical decision tasks. We suggest that this processing may entail maintenance of the accessed item in short-term memory. If evidence for the syllable's internal organization and for the influence of the sonority hierarchy on that organization emerges only in tasks that require the maintenance of information in short-term memory, and if lexical decision requires such maintenance, then it is not surprising that our results supporting syllable-internal structure emerged only in the lexical decision task.

However, we found support only for the breakdown of the rime into a peak and a coda, whereas Treiman and Chafetz (1987) found, also using a lexical decision task, that subjects responded more rapidly to visually presented words and nonwords when slashes appeared between the onset and the rime than when they appeared between the peak and the coda. There are at least two possible sources for this discrepancy. In the first place, they compared visual interruptions after the onset and after the peak within the same set of words and nonwords, whereas we used different words to test the strength of the onset–rime boundary and the nucleus–coda boundary. We thus could not compare directly the strength of these two boundaries. Second, we found an unanticipated, significant effect of onset type, apparently related to the frequency of the stimulus items, that may have effectively masked differences between interruptions that occurred within the onset and those that occurred between the onset and the rime and that may have also conceivably masked an interaction of the sonority hierarchy with syllable structure. In any event, given the pattern of our other results, we would predict an onset–rime boundary effect to emerge only postlexically, in a lexical decision task or other task requiring maintenance of information in short-term memory.

Fowler (1987) and Browman and Goldstein (1988) have argued that the syllable's internal structure may arise as a result of articulatory constraints on the timing of initial vs. final consonants with respect to vowels in the same syllable. Because the phonological code required to maintain information in short-term memory is more strongly affected by articulatory suppression than the phonological code permitting lexical access (according to Besner and Davelaar, 1982), it would seem reasonable to suggest that it too has an articulatory basis (see, e.g., Hintzman, 1967). In any event, the results of our experiments taken in conjunction with prior psycholinguistic research on the internal structure of the syllable and the sonority hierarchy would suggest the following: Support for the hierarchical structure of the syllable and for the influence of the sonority hierarchy on such structure is most likely to emerge in tasks that implicate phonological coding in short-term memory.

APPENDIX: TEST ITEMS USED IN EXPERIMENTS 1 AND 2

Onset–rime

C_1C_2 = 1 phoneme		C_2 = liquid		C_2 = nasal	
Word	Nonword	Word	Nonword	Word	Nonword
chest	chorn	craft	flaft	smart	snart
thorn	thest	flint	crint	smash	snash
chill	chigh	drank	glank	sniff	smiff
thigh	thill	glint	drint	snarl	smarl
shark	sheft	clasp	blasp	smell	snell
theft	thark	blend	clend	snuff	smuff
shunt	shump	prank	trank	C_2 = obstruent	
chump	chunt	tramp	pramp	stern	spern
shawl	chawl	plump	brump	spasm	stasm
champ	shamp	brand	pland	skunk	scunk
thumb	shumb	clink	grink	scowl	skowl
shirt	thirt	grind	clind	stark	scark
				skimp	stimp

Nucleus–coda

C_3 = obstruent		C_3 = liquid		C_3 = nasal	
Word	Nonword	Word	Nonword	Word	Nonword
blast	crasp	dwarf	smarf	blunt	swunt
crisp	blisp	smirk	dwirk	swamp	blamp
brisk	crisk	scald	scort	blank	slank
crust	brust	snort	snald	slump	blump
cleft	greft	scalp	scern	print	clint
grist	clist	stern	stalp	clump	prump
draft	twaft	spark	skark	stint	blint
twist	drist	skirt	spirt	blond	stond
tract	traft	sport	sporm	blink	blant
graft	gract	storm	stort	scant	scink
grasp	frasp	spurt	spirl	trunk	trand
frost	grost	swirl	swurt	brand	brunk

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