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Attentional Allocation to Syllables in American English

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Previous experimental studies in speech perception (e.g., Cutler, Mehler, Norris, & Seguí, 1986) have concluded that the syllable is not a prelexical segmentation unit for English speakers. The set of experiments reported here applied the attentional phoneme monitoring task of Pallier, Sebastián-Gallés, Felguera, Christophe, and Mehler (1993) to American English and demonstrated a robust effect of syllable structure when second-syllable stress words were used, but no such effect with first-syllable stress words. We hypothesize that aspects of syllable structure related to word stress are an important factor in the detection of syllabic effects in English.

In order to access the mental lexicon and comprehend spoken language, the speech stream must be segmented into meaningful units such as words or morphemes. Processing considerations have led to the hypothesis that the speech stream might be initially segmented into smaller, pre-lexical representational units which then serve as the basis for lexical access (for discussion, see Pisoni & Luce, 1987); phonemes and syllables are the most frequently proposed candidates. Logical arguments can be made for each of these units: the inventory of phonemes in a language is fairly small, so the procedures which perform a segment-by-segment comparison of the input with the representation in the mental lexicon would only need to deal with a small set of units. This potential efficiency is, however, counteracted by the effect of coarticulation, which makes the acoustic realization of a given phoneme in the speech stream highly variable depending on context (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967). In contrast, the inventory of syllables in a language is necessarily larger than the number of phonemes (by orders of magnitude in languages with a complex syllable structure such as English). However, coarticulatory effects may be less problematic with a syllabic segmentation mechanism, since the intra-syllable coarticulation would be part of the syllabic representation, and thus simply part of the matching process rather than noise.

One experimental approach to this issue has involved investigating the relative sensitivity of listeners to phonemes and syllables. Beginning with Savin and Bever (1970), researchers have compared performance in syllable monitoring tasks to that in phoneme monitoring tasks to determine whether syllabic representations are built up from phonemes, or whether phonemes (when required by task demands) are extracted from syllables. Norris and Cutler (1988) contains a survey of this literature, as well as a discussion of some methodological problems which compromise the conclusions that have been drawn from this body of work.

A slightly different approach has also used monitoring tasks to search for specific evidence that a given unit is available during the course of speech processing. Mehler, Dommergues, Frauenfelder, and Seguí (1981) used

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a syllable monitoring technique to investigate the role of the syllable in speech segmentation. Subjects were asked to respond when a particular visually-presented target phoneme sequence occurred in a spoken word; the manipulation of interest was whether the phoneme sequence corresponded to a full syllable in the word or not. For example, the consonant–vowel (CV) sequence /ka/ is an initial syllable in the French word ''ca-rotte,'' but is only part of a syllable in the word ''car-ton.'' However, the CVC sequence /kar/ is a full syllable in the word ''car-ton,'' but overlaps two syllables in the word ''ca-rotte.'' Mehler et al.'s results showed a strong interaction of target type and syllable structure, indicating that monitoring in the task was faster when there was a match between target and syllable than when there was not a match. This is consistent with the hypothesis that listeners are sensitive to syllabic structure and was taken as support for the hypothesis that the syllable is a unit of segmentation in French (and, possibly, a unit of lexical access).

Since syllables exist in all languages, it is plausible that the syllable might be a universal segmentation unit. However, further investigations using this syllable monitoring task have shown an interesting range of cross-language variation, suggesting that the unit of segmentation might depend on the language involved. Cutler, Mehler, Norris, and Seguí (1986) found no evidence for any syllabic effect with British English subjects and materials. Sebastián-Gallés, Dupoux, Seguí, and Mehler (1992) found a syllable match effect for Catalan with second-syllable stress words, but no evidence for syllabic effects in Spanish unless subjects' response times were slowed by a secondary task. However, Bradley, Sánchez-Casas, and García-Albea (1993) found a strong interaction of target type and syllabic structure in Spanish, while their results for Australian English showed an overall advantage for CVC targets, but no interaction; such a CVC advantage is consistent with some approaches to syllabic segmentation. A similar CVC advantage for American English was reported by Allopenna (1995). Finally, Zwitserlood, Schriefers, Lahiri, and van Donselaar (1993) found syllabic effects for Dutch (a Germanic language with some of the phonological characteristics of English).

What characteristics of these languages might cause this variation? French is usually described as a syllable-timed language having clear syllabic boundaries; stress is typically word final. Spanish is described as having clear syllables like French, but a smaller vowel inventory and hence a smaller inventory of syllables. The clear syllabification of these two languages might encourage syllabic strategies, though, as noted, there are conflicting results for Spanish. However, determination of syllable boundaries in stress-timed English is less straightforward. Based on phonological considerations, Kahn (1980) concluded that medial consonants in certain contexts in English (e.g., following a stressed syllable) are ambisyllabic, that is, belong to two syllables at once (see also Anderson & Jones, 1974). In this view, the ''l'' in English ''balance'' functions simultaneously as the coda of the first syllable and the onset of the second syllable. Direct experimental evidence bearing on this was provided by Treiman and Danis (1988), who used an offline task and found that subjects gave ambivalent responses about the syllabic membership of such intervocalic consonants.

Cutler et al. (1986) hypothesized that such syllabic ambiguity could interfere with English speakers' use of syllable based routines (though note that the results of Zwitserlood et al., 1993, suggest that syllabic segmentation can occur in languages with ambisyllabic consonants). Thus, English speakers might not use a syllabic segmentation strategy (even though French speakers do), but might instead use a phoneme-based strategy.

Pitt and Samuel (1990) provided some preliminary evidence in support of the phoneme as a perceptual unit in English, making use of attentional manipulation in a phoneme-monitoring task. Based on the assumption that one form of evidence for a perceptual unit would be the ability to focus attention on that unit, they manipulated the expected location of a phoneme target by embedding experimental words in lists in which the majority of words had the target in a given serial (linear) phoneme position. Such induced expectation (''attention'') has been shown to affect reaction time (RT) in experimental tasks; various studies (primarily in the visual modality, see, e.g., Posner & Snyder, 1975) have shown that valid expectations result in decreased RTs. Pitt and Samuel's results showed that consonant monitoring in English was facilitated for a given serial position when attention was directed to that position, providing support for the hypothesis that the phoneme is a unit of perception.

However, Pallier, Sebastián-Gallés, Felguera, Christophe, and Mehler (1993) pointed out that the structure of the experimental materials of Pitt and Samuel (1990) confounded serial phoneme position with syllabic position: test words in the Pitt and Samuel study all had CVC-CVC structure (e.g., ''fac-tor''), so a given serial position was always in the same syllabic position (e.g., the third serial phoneme was always in a syllable coda). Therefore, Pitt and Samuel's results cannot be taken as unambiguous evidence for the phoneme as a unit of segmentation, since the results might also be interpreted as induction of attention to a subsyllabic unit (i.e., the coda or onset of the syllable), and are thus consistent with a syllabically structured representation. Pallier et al. proposed a manipulation that would distinguish the syllabic hypothesis from the phonemic hypothesis using an attentional paradigm and applied this approach to French and Spanish. Words were selected in which the target phoneme occurred in the third serial position but belonged to either the coda of the first syllable (''coda words,'' starting with CVC-CV, e.g., French ''caP-tif''), or in the onset of the second syllable (''onset words,'' starting with CV-CCV, e.g., ''ca-Price''). Test words of both structures were embedded in induction lists which contained predominantly onset words in one condition and coda words in a second condition. A phonemic hypothesis would predict that there should be no difference between the two classes of test words across induction conditions, since the test phoneme was in the third serial position in all cases. However, if attention is in fact induced to syllabic position, an interaction between test word type and induction condition would be expected. The results of Pallier et al. supported the syllabic hypothesis. For both French and Spanish, RTs were faster when the test words matched the syllabic inductor type; i.e., the subsyllabic units were responsible for the effect, not the serial position. In addition, because their data showed a robust effect in a detection task in Spanish (a language that had given mixed results in other studies), they suggested that this attentional task might be a better diagnostic for listeners' sensitivity to syllabic representations than the syllable monitoring task. Furthermore, results from an experiment using pseudo-words indicated that these syllabic effects were not based on a lexical representation (Pallier et al., 1993).

The sensitivity of this task to syllabic position supports Pallier et al.'s argument that Pitt and Samuel did not unambiguously establish that the phoneme is a unit of prelexical processing in English. One goal of the experiments reported here is to apply the technique of Pallier et al. to American English to determine whether this technique will demonstrate a syllable effect in English. The detection of a syllabic effect with this paradigm in French and Spanish is perhaps not surprising, since these are clearly syllabified languages; the ambisyllabicity of English makes it a more interesting case.

We also address a second important issue: the extent to which the previous results for English might be dependent on the stress patterns of the words chosen. The syllable monitoring studies on English cited above (Bradley et al., 1993; Cutler et al., 1986) have used words with first-syllable stress. Theoretical arguments in Kahn (1980) have suggested that word-internal syllabification is clearer in words with second-syllable stress than in words with first-syllable stress; e.g., the intervocalic /k/ in ''racoon'' is clearly associated with the second syllable, unlike the intervocalic /k/ in ''racket.'' Thus, it may be incorrect to state that English does not show any syllabic effects at all; perhaps English will show them in some contexts (e.g., where syllabification is clear) but not others.

Syllabic effects contingent on stress patterns would also be relevant to one current proposal for lexical access in English: the Metrical Segmentation Strategy (MSS) described in Cutler and Norris (1988) and Cutler (1990). Effects of the sort found by Pallier et al. (1993), which distinguish between the coda of the first syllable and the onset of the second syllable, would seem to require location of the boundary between the two syllables. In the MSS proposal, segmentation in English (and the initial attempt at lexical access) occurs only before strong syllables (i.e., syllables with an unreduced vowel, such as stressed syllables). Since the initial syllable sequence in second-syllable stress words in English is typically weak–strong, evidence for a syllabic effect in this case would be consistent with the MSS proposal that segmentation occurs before strong syllables (though a fully specified MSS account must also include on-line identification of the precise boundary preceding a strong syllable, based on the phonology of the language). Any evidence for an attentional syllabic effect in first-syllable stress words (with a strong–weak syllable structure) might, however, be taken as counterevidence to the MSS since the MSS does not predict segmentation preceding weak syllables.

The experiments described here used a procedure that closely followed that of Pallier et al. (1993): the targets for phoneme monitoring were in the third phoneme position, and sets of test words were chosen such that the target phoneme occurred in the onset of the second syllable (‘‘de-Bris’’) or the coda of the first syllable (‘‘suB-due’’). Both onset and coda test words were embedded in separate onset and coda induction lists, which were formed by including a number of additional trials of either onset or coda form. One elegant aspect of this design is that baseline differences between onset and coda words (such as frequency and response time) should not affect the results, since the same test words are used in all conditions. Induction condition was a between-subjects factor, but each subject responded to both onset and coda test words. The procedure and stimuli are described in detail for Experiment 1, while further Methods sections describe only the changes from this description.

Experiment 1

Method

Stimuli. The words used in Experiment 1 all had second-syllable stress and began with a single consonant; *Webster's II New Riverside University Dictionary* (1984) was used as the primary source. Most words were bisyllabic, though some three syllable words were included; compounds and other multimorphemic words were avoided as far as possible because of possible effects on perceived syllable boundaries. We created two lists of words with an initial CVCCV sequence, one containing onset words (in which the third phoneme, a consonant, occurred in the onset of the second syllable, e.g., ‘‘re-Gression’’), and one with coda words (where the third phoneme was in the coda of the first syllable, e.g., ‘‘maG-netic’’). Syllabifications were taken from the dictionary entries; these typically followed a maximal onset rule. Target phonemes in coda words were necessarily followed by another consonant (if they were not, the maximal onset rule would have placed the target phoneme in the onset of the second syllable), and we followed Pallier et al. (1993) in having a consonant follow the target phoneme in onset words as well, leading to the use of medial consonant clusters in the onset words.

Target phonemes for the test words were the voiced and voiceless stop consonants /g/ and /k/, and /b/ and /p/ (these stops allow formation of clusters in English with both of the liquids /l/ and /r/). Sixteen onset test words and 16 coda test words were chosen, matched in target phoneme and number of syllables (see the Appendix for a complete list of materials). Frequency of the words was not considered; as noted above, matching such variables in this task is not necessary. The resulting set of test words included four pairs of targets using ''b,'' three using ''p,'' three using ''g,'' and six using ''k.''

Fifty onset inductor words and 50 coda inductor words were also selected. The target sounds in these inductor words were chosen from a wider range of phonemes: stops (all six), nasals, fricatives, and liquids. Thirty-two words (16 each of onset and coda form) were chosen as distractors, to be used with target phonemes that did *not* occur in the word.

The experimental list in an induction condition consisted of all 32 test words (16 each of onset and coda form), the 32 distractor words (16 onset and 16 coda), and 50 inductor words (onset words in the onset induction condition, and coda words in the coda induction condition); this gave a total of 114 words in each list. Experimental lists were constructed pseudo-randomly, subject to the following constraints. The 32 target words and 32 distractor words were placed in the same positions in each experimental list. No two target items occurred in succession, there being at least one inductor word preceding each target word. No target words occurred in the first eight trials, which contained six inductor words and two distractor words. The same list was presented to all subjects within a given condition.[1]

The stimulus words were recorded in random order onto a DAT recorder by a male native speaker of American English; they were then sampled at 20 KHz and stored on the disk of a Gateway 2000 computer. The onset of the burst of the stop consonant target in each of the 32 test words was identified visually using a waveform editor, and a mark was placed which triggered the clock for measuring response time.[2]

Procedure. A trial consisted of a 1 s visual presentation on a computer screen of a capital letter representing the target phoneme, followed after 1 s by audio presentation of a word over headphones at approximately 78 db SPL. A new trial started 2.5 s after the subject's response. The entire presentation of 114 words was uninterrupted and took less than 15 min.

Subjects were tested individually in a sound-attenuated room; they sat facing a video monitor placed at eye level approximately 46 cm away. The response box consisted of two buttons, labeled YES and NO; subjects used one hand on each button, with the YES button assigned to their dominant hand.

Subjects were given written instructions describing the task; these explicitly instructed subjects to think of the sound that the visually presented letter represented. For example, the phoneme /k/ was represented by ''K,'' and this letter was used as an example in the instructions (''K as in 'wreckage' ''). Subjects were instructed to respond by pressing the YES button if they heard the target sound in the test word, and the NO button if not, and to respond as quickly and accurately as possible without waiting for the end of the word. There were no explicit practice trials, but no test items occurred during the first eight trials.

Subjects. Twenty members of the Brown University community, all native speakers of English, were paid for their participation in this experiment. Over the series of experiments reported here, subjects typically partici-

[1] In addition to the two conditions of primary interest (coda and onset induction), a third (control) condition was also employed (with 10 additional subjects), in which half the inductors were coda words and half were onset words. The purpose of this condition was primarily to provide a neutral baseline for an analysis of facilitation and inhibition. However, this condition failed to provide consistent findings and consequently will be omitted from further consideration, with one exception in the final discussion.

[2] Placing such a mark is not always trivial for English, particularly in the case of coda words with two adjacent stops (e.g., ''dic-tation''), where there may not be a clear burst indicator in the period between the vowel and the release for the second stop. In such cases, we tried to find some sort of distinguishing mark for the target stop in the signal during this period, although this decision was sometimes close to arbitrary. However, since these timing marks were the same in both induction conditions, the effect of any misplaced marks would be the same across conditions, and any differences between induction treatments would be unaffected.

TABLE 1

MEAN RESPONSE TIMES (SDs) IN MILLISECONDS AS A FUNCTION OF INDUCTION CONDITION AND TARGET TYPE (EXPERIMENT 1: SECOND-SYLLABLE STRESS WORDS)

Induction condition	Onset targets	Coda targets
Onset	520 (152)	588 (177)
Coda	642 (275)	557 (268)

pated in only one experiment, although this was not strictly enforced when a long period (6 months) separated the experiments.

Results

Incorrect responses were excluded from the analysis, as were RTs greater than 2000 ms or less than 100 ms. Data omitted for these reasons comprised 3.3% of the responses. In the onset induction condition, onset targets had a mean RT 68 ms faster than the coda targets. In the coda induction condition, however, RTs to onset targets were 85 ms *slower* than coda targets. Average RTs and standard deviations are given in Table 1.

Analyses of variance (Induction condition by Target type) were carried out with both subjects (F_1) and items (F_2) as random variables, and no reliable main effects were found (throughout this paper, results will be considered reliable only if $p < .05$ for both the subjects and items analysis). However, the interaction of induction condition and target word type was highly significant ($F_1(1,18) = 17.11$, $p < .001$; $F_2(1,30) = 19.29$, $p < .001$). Thus, the two induction conditions differentially affected RTs for the two classes of words. Simple effects were examined by performing *t* tests for the data within each induction condition. The 85 ms advantage of coda over onset words within the coda induction condition was significant ($t_1(9) = 3.6$, $p = .006$; $t_2(30) = 2.83$, $p = .008$). The 68 ms advantage of onset over coda words within the onset induction condition was significant in the subjects analysis and nearly significant in the items analysis ($t_1(9) = 2.38$, $p = .04$; $t_2(30) = 1.97$, $p = .06$).

Discussion

As would be predicted by a syllabic hypothesis, there was a significant effect of induction to syllabic position in American English, even when all target phonemes occurred in the third serial position. These results resemble the results of Pallier et al. (1993) with French and Spanish and support the hypothesis that expectation induced for a particular subsyllabic position affects RT in a phoneme monitoring task in English.

These findings provide support for the hypothesis of syllabic representation in English. However, it is possible that some other difference between onset and coda words might have been responsible for the effect. One possibility is that the effect of attentional manipulation found in Experiment 1 might have been due to fine-grained temporal attention (expectation of an early or late target) rather than attention to syllabic structure. Investigation of the stimuli showed, in fact, that the difference in temporal position of the target phoneme relative to the word beginning was considerable in the two classes of words. The mean temporal position of the target phoneme was 179 ± 53 ms in the onset test words, and 224 ± 43 ms in the coda test words. Furthermore, those inductor words which contained easily marked stops (33 in the onset condition, 18 in the coda condition) also showed a corresponding difference between the target phoneme position in the onset and coda words (onset: 166 ± 45 ms, coda: 213 ± 42 ms). In both inductors and test words, the phoneme target appeared later in coda words than in onset words, and this could have been the source of the effect in Experiment 1. Experiment 2 addressed the possibility of temporal (as opposed to syllabic) attention by using stimuli that were spliced to remove this temporal difference.

EXPERIMENT 2

Method

Stimuli. The audio files of Experiment 1 were digitally edited to remove the temporal differences described above. In each of the onset words (targets and inductors), approximately 20 ms was added in the region preceding the target phoneme by repeating one or more vowel periods, extending a sibilant, or extending a stop closure. Twenty milliseconds was removed from each coda word (target and inductor) by removing one or more vowel periods, shortening a sibilant, or shortening a stop closure. Following this editing, the mean difference in temporal position of the target was substantially reduced (and now in the opposite direction) in the two test word groups (onset: 201 ± 49 ms, coda: 188 ± 36 ms) and eliminated in the inductor groups (onset: 183 ± 40 ms, coda: 183 ± 34 ms). The edited audio files were substituted for the original files; the list order was unchanged.

To verify that the edited stimuli did not sound artificial, we tested whether they could be distinguished from the unedited simuli in an AXB task. Ten subjects were presented with three repetitions of a target word, where the middle repetition was matched by either the first presentation or the third presentation; subjects made a forced choice. For each of the 32 target words, a subject heard all four groupings of spliced and unspliced stimuli. The subjects could not reliably distinguish between the spliced and unspliced targets; the mean d' was 0.4.

Procedure. The procedure was identical to that used in Experiment 1.

Subjects. Twenty members of the Brown University community, all native speakers of English, were paid for their participation in this experiment.

Results

Responses (5.3%) were excluded from the analysis due to error or extreme RTs, as described in Experiment 1. In the onset induction condition, onset targets were responded to 146 ms faster than coda targets. In the coda induction condition, onset targets were responded to 31 ms slower than coda targets (see Table 2).

Analyses of variance on the coda and onset induction conditions showed no reliable main effects. However, the interaction of induction condition and target word type was again highly significant ($F_1(1,18) = 14.46, p = .001$; $F_2(1,30) = 21.12, p < .001$).

TABLE 2

MEAN RESPONSE TIMES (SDs) IN MILLISECONDS AS A FUNCTION OF INDUCTION CONDITION AND TARGET TYPE (EXPERIMENT 2: SPLICED WORDS)

Induction condition	Onset targets	Coda targets
Onset	677 (215)	823 (294)
Coda	652 (245)	621 (193)

A test for simple effects was performed using a t test for the data in each induction condition. The 146 ms advantage of onset over coda words within the onset induction condition was highly significant ($t_1(9) = 3.59, p = .006$; $t_2(30) = 3.52, p = .001$). However, the 31 ms advantage of coda over onset words within the coda induction condition was not significant ($t_1(9) = 1.36, p = .21$; $t_2(30) = .67, p = .61$).

Inspection of the data from Experiments 1 and 2 suggests that RTs in the onset induction condition were slower in Experiment 2 than in Experiment 1. An analysis of variance combining the onset induction condition data from Experiments 1 and 2, and including experiment as a factor, indicates that this is in fact the case: the average RT for pooled targets in the onset induction condition is 554 ms in Experiment 1 and 750 ms in Experiment 2, and this difference is significant ($F_1(1,18) = 4.40, p = .05$; $F_2(1,30) = 187.15, p < .001$). We do not have any principled explanation for this; it appears to be due to a few slow subjects in Experiment 2.

However, the *interaction* of induction group and target word type did not differ significantly across these two experiments; a three-way analysis of variance with experiment, induction group, and target type as factors did not reveal a significant three-way interaction ($F_1(1,36) < 1$; $F_2(1,30) < 1$).

Discussion

The results of Experiment 2 showed that even after stimulus words were edited to equate the time between word onset and target, there was still a differential effect of induction condition on phoneme monitoring times in the two groups of target words. The interaction obtained in Experiment 1 was not due to temporal expectation, and the syllabic hypothesis is supported.

However, before accepting the syllabic explanation of these results, a further possible explanation must be ruled out. In our materials, all of the onset test words involved a phoneme that was the first phoneme in a stop-liquid cluster, and the onset inductor words also involved clusters. In an experiment involving word-initial phonemes, Cutler, Butterfield, and Williams (1987) found that phoneme monitoring times were affected by the context (''model'') in which the target phoneme was presented, i.e., a C target presented (auditorily) in a CV model (e.g., '' 'p' as in 'pink' '') was detected faster in a word-initial CV sequence than in a word initial CC sequence, whereas a C presented in a CC model (e.g., '' 'p' as in 'plate' '') was detected faster in a corresponding CC sequence than in a CV sequence. In a similar fashion, stops at beginnings of clusters in our materials might have been easier to detect when subjects were expecting clusters (based on their high frequency of occurrence in the onset induction condition), and the results of Experiment 1 may not reflect attention to position in a syllable, but rather some form of phonological or acoustic expectation. This possibility was addressed in Experiment 3.

Experiment 3

To determine whether expectation of a cluster was responsible for the results of Experiment 1, we replaced the 16 CV-CCV onset test words in both experimental lists with words having an initial CV-CV sequence; inductors and coda test words were not changed. If the induction effect involving the onset induction conduction is based on expectation of clusters, then this change should eliminate the induction effect in the onset induction condition, leading to a smaller, perhaps nonsignificant, interaction effect in this experiment. We would not necessarily predict that the interaction would disappear completely, as there might still be an effect within the coda induction condition.

TABLE 3

Mean Response Times (SDs) in Milliseconds as a Function of Induction Condition and Target Type (Experiment 3: Single-Phoneme Onset Words)

Induction condition	Onset targets	Coda targets
Onset	571 (136)	701 (194)
Coda	629 (254)	636 (288)

Method

Stimuli. Sixteen new onset test words starting with a CV-CV sequence were used in place of the onset test words of Experiment 1. These new words were also stressed on the second syllable and were matched to the Experiment 1 words in target phoneme and number of syllables (e.g., ''report'' in place of ''reply''). In addition, 5 of the 16 onset distractors were also changed to be of CV-CV form (see the Appendix for stimulus lists). The new words were recorded by the same speaker who recorded the materials in Experiment 1. The recordings were digitized, and the new files inserted into the appropriate corresponding positions in the lists of Experiment 1.

Procedure. The procedure was identical to that used in Experiment 1.

Subjects. Twenty members of the Brown University community, all native speakers of English, were paid for their participation in this experiment.

Results

Responses (3.8%) were excluded from the analysis due to error or extreme RTs. In the onset induction condition, onset words were responded to 130 ms faster than coda words: In the coda induction condition, onset words were also responded to faster than coda words, though only by 7 ms (see Table 3).

Analyses of variance showed that the 68 ms main effect for target word type was significant ($F_1(1,18) = 11.56$, $p = .003$; $F_2(1,30) = 4.82$, $p = .04$); the main effect of induction condition was not significant. Most importantly, the interaction of induction condition with target word type was again significant ($F_1(1,18) = 9.32$, $p = .007$; $F_2(1,30) = 11.17$, $p = .002$).

A test for simple effects was performed using a t test for the data in each induction condition. The 130 ms advantage of onset over coda words within the onset induction condition was significant ($t_1(9) = 3.73$, $p = .005$; $t_2(30) = 3.67$, $p = .001$). The 7 ms advantage of onset over coda words within the coda induction condition was not significant ($t_1 = .34$; $t_2 = .11$).

Compared with Experiment 1, there appears to be a markedly reduced effect in the coda induction condition, but an increased effect in the onset induction condition. This is clearly counter to the prediction that the onset effect would be reduced as a result of the cluster manipulation. To test the nature of the overall interaction between Experiments 1 and 3, we performed a three-way analysis of variance on the combined data of the two experiments with experiment, induction condition, and target type as factors. The three-way interaction was not significant, suggesting that there was no reliable difference in the overall interaction of induction condition and target word across these two experiments ($F_1(1,36) = .29$, $p = .59$; $F_2(1,30) = .13$, $p = .72$).

Discussion

Although all the onset induction words in this experiment contained medial consonant clusters, and none of the onset target words did, there was nonetheless an interaction of induction condition with target word type, and this interaction did not differ from that in Experiment 1. Thus, the attentional effect does not appear to be due to induction based on the presence of consonant clusters. Experiments 1–3 converge to demonstrate the presence of a syllabic effect in a word-internal phoneme monitoring task in English.

In each of Experiments 1, 2, and 3, all subjects in an induction condition received the same experimental list ordering, and placement of the actual target words in the lists was identical in all conditions in all three experiments. Although the lists were constructed pseudo-randomly, the consistent results might have been an artifact of the exact list ordering used. To verify that this was not the case, we performed a replication of Experiment 1 using lists which were separately randomized for each subject, and in which the stimulus ordering constraints of Experiment 1 were not applied. Ten subjects were tested in each condition.

A two-way analysis of variance of the results with Induction condition and Target type as factors revealed that the interaction of these variables was again significant, as in Experiment 1 ($F_1(1,18) = 11.27$, $p = .004$; $F_2(1,30) = 11.96$, $p = .002$). Thus, the syllabic effect was not an artifact of the list ordering.

EXPERIMENT 4

None of the reported experiments has yet provided data about the locus of the representation used in this task, that is, whether it is a pre- or post-lexical representation. It is possible that syllable structure is available only after the lexical entry has been contacted; if this is the case, the above data have no bearing on the issue of pre-lexical units of segmentation. To make the argument that the syllabic effects we have demonstrated are not post-lexical in nature, Experiment 4 used the approach of Cutler et al. (1986), Pallier et al. (1993), and Pitt and Samuel (1990) and tested whether the syllabic effect would occur with nonwords that follow the phonotactic rules of the language, but which have no lexical entry.

Method

Stimuli. All the target words of Experiment 1 (onset and coda) were replaced by pseudo-words. In order to keep as much similarity across experiments as possible, pseudo-words were formed by changing the first phoneme of each target word to form a nonword;[3] the pronunciation of the pseudo-words was modeled on the words they were derived from (e.g., ''tosmetic'' rhymed with ''cosmetic''). Five out of 16 distractors in each word class (onset and coda) were also replaced with similarly derived pseudo-words. The modified targets and distractors are listed in the Appendix; inductors were unchanged from Experiment 1.

Procedure. The procedure was identical to that used in Experiment 1.

Subjects. Twenty members of the Brown University community, all native speakers of English, were paid for their participation in this experiment.

Results and Discussion

Responses (7.8%) were excluded due to error or for having extreme RTs. In the onset induction condition, onset targets were responded to 73 ms faster than coda targets. There was only a 1 ms difference in the two target types in the coda induction condition (see Table 4).

Analyses of variance showed no significant main effects. However, the interaction of induction condition and target word type was significant ($F_1(1,18) = 7.24$, $p = .015$; $F_2(1,30) = 7.53$, $p = .01$). Simple comparisons using a t test in each induction condition showed that the 73 ms advantage of onset over coda words within the onset induction condition was significant ($t_1(9) = 3.65$, $p = .005$; $t_2(30) = 2.28$, $p = .03$). However, the 1 ms advantage of onset over coda words within the coda induction condition was not significant ($t_1 = .06$; $t_2 = .19$).

TABLE 4

MEAN RESPONSE TIMES (SDs) IN MILLISECONDS AS A FUNCTION OF INDUCTION CONDITION AND TARGET TYPE (EXPERIMENT 4: PSEUDO-WORDS)

Induction condition	Onset targets	Coda targets
Onset	638 (184)	711 (166)
Coda	657 (223)	658 (256)

The syllabic induction effect occurred even when the target words were pseudo-words, showing that a lexical representation was not the source of the syllabic effect.

EXPERIMENT 5

Experiments 1–4 provide evidence for a syllabic effect in speech perception in English, in contrast to previous studies (e.g., Cutler et al., 1986) which have argued against the existence of such an effect. One possible source of this difference in results is the use of second-syllable stress words in Experiments 1–4, in contrast to the use of first-syllable stress words in Cutler et al. In Experiment 5 we investigated this possibility by applying the methodology of Experiments 1–4 to first-syllable stress words in American English. If the difference in results between our study and those of Cutler et al. is strictly a methodological one (i.e., the attentional technique is more sensitive in some way than syllable monitoring, as Pallier et al., 1993, claimed), a syllabic effect might be expected with first-syllable stress words. Alternatively, if the difference is related to word stress, then there should be no effect of syllabic induction on response to first-syllable stress word targets in the attentional paradigm.

Method

Stimuli. The stimuli for this experiment were first-syllable stress words with initial

[3] One possible concern is whether such changed stimuli might nonetheless access the base lexical item. Frauenfelder, Seguí, and Dijkstra (1990) provide data suggesting that a change in the first phoneme precludes contact with the lexicon, and Marslen-Wilson (1990) mentions studies which suggest that this is true even when the change is small, e.g., the voicing change between /p/ and /b/. However, Milberg, Blumstein, and Dworetzky (1988) and Connine, Blasko, and Titone (1993) argue that there may be at least some contact with the lexicon when the first phoneme change involves only one or two features. Though we cannot decisively resolve this issue here, our materials almost always involved a change in place of articulation (e.g., /d/ to /g/, which in binary feature systems will usually alter multiple features), and often an additional feature change, rather than the single feature change in many of the stimuli of Connine et al.

CVCCV sequences. The majority of these were again taken from the *Webster's II New Riverside Dictionary* (1984). A distinction arose which did not occur with second-syllable stress words: first-syllable stress words plausibly syllabified as CV-CCV (i.e., onset words, where the medial consonant pair forms a legal onset cluster) come in two classes, those containing a long (or tense) vowel in the first syllable (e.g., ''cyclist''), and those with a short (or lax) vowel (e.g., ''macro''). There is some evidence that the syllabifications in these two cases might be different, with the third phoneme ambisyllabic when the vowel is short (Kahn, 1980) but belonging only to the onset of the second syllable when the vowel is long. This theoretical claim has a correlate in dictionary syllabification; for example, the Webster's II dictionary lists two pronunciations for ''cyclic,'' with different first-syllable vowels, and different syllabifications (''sī′ klĭk'', ''sĭk′lĭk''). For Experiment 5, we used materials in which onset words (targets, inductors, and distractors) were evenly divided among the two vowel types.

All target words (onset and coda) again used the voiced and voiceless stops /g/ and /k/, and /b/ and /p/. We chose four pairs of target words with each of these four phonemes, for a total of 16 onset and 16 coda target words. Thirty-two distractor words were also chosen, as well as 50 onset induction and 50 coda induction words. Experimental lists were constructed according to the criteria in Experiment 1; materials are provided in the Appendix.

Procedure. The procedure was identical to that used in Experiment 1.

Subjects. Twenty members of the Brown University community, all native speakers of English, were paid for their participation in this experiment.

Results

Responses (6.3%) were excluded due to error or extreme RTs. The results from this experiment are given in Table 5. In the onset induction condition, onset words were responded to 59 ms faster than coda words. In the coda induction condition, onset words were responded to 20 ms faster than coda words.

TABLE 5

MEAN RESPONSE TIMES (SDs) IN MILLISECONDS AS A FUNCTION OF INDUCTION CONDITION AND TARGET TYPE (EXPERIMENT 5: FIRST-SYLLABLE STRESS WORDS)

Induction condition	Onset targets	Coda targets
Onset	610 (202)	669 (185)
Coda	590 (236)	610 (212)

A two-way analysis of variance with Induction condition and Word type as factors produced no reliable main effects. In addition, the interaction of induction condition and target word type was not significant ($F_1(1,18) = 1.53$, $p = .23$; $F_2(1,30) = 1.72$, $p = .20$).

Discussion

The absence of an interaction in this experiment contrasts with the significant interaction found in each of the first four experiments, where second-syllable stress materials were used. When first-syllable stress words were used in this phoneme monitoring task, there was not a significant differential effect of induction condition on words with targets in different subsyllabic positions.

Interpretation of the results is complicated by the two different word types used in the onset class. Although words with long vowels such as ''cyclist'' can be argued to have a clear syllable boundary following the first vowel (Myers, 1987), the /b/ following the short vowel in ''fabric'' is considered to be ambisyllabic in proposals such as Kahn (1980). Such ambisyllabicity might mean that the first syllable in such ''onset'' words has a CVC structure, or that the syllable boundary is unclear; in either interpretation, the induction in the onset condition in Experiment 5 (where short and long vowels were mixed) is unclear, and is a possible cause of our failure to find an induction effect. However, there is additional evidence that syllabic induction effects do not occur with first-syllable stress words, at least those with short vowels. Pallier (1994) reported an experiment which applied the attentional paradigm to American English, and which used first-syllable stress words with short vowels (i.e., materials similar to those used by Cutler et al., 1986). Pallier found no effect of syllabic induction. Thus, there is converging evidence that the attentional phoneme monitoring task does not show syllabic effects with such first syllable stress materials. It remains an open question whether the use of onset inductors and targets with long vowels (where syllabification may be unambiguous) would produce a syllabic induction effect.

General Discussion

We undertook this series of experiments to investigate whether syllabic effects could be demonstrated in English using an attentional paradigm. The results we report are the first instance we know of in which unambiguous syllabic effects have been reliably found in an on-line task using English materials and subjects.

Experiment 1 showed that experimentally induced expectations about the syllabic position of a target phoneme affected RT in a phoneme-monitoring task using second-syllable stress words. This suggests that the system underlying speech perception is sensitive to syllable structure in English. Experiment 2 showed that the temporal difference between the target location in the two classes of words (onset and coda) was not responsible for this effect. Experiment 3, using onset target words with an initial CV-CV structure, also showed the interaction found in Experiment 1, arguing against an explanation based on the expectation of a consonant cluster. Experiment 4 showed that a similar interaction occurred with second-syllable stress pseudo-words, supporting the hypothesis that the effect occurred at a prelexical level of processing.[4]

Experiments 1–4 used materials in which primary word stress was on the second syllable and yielded results consistent with the hypothesis that induction of attention to a syllabic position affects phoneme monitoring times. Experiment 5, using first-syllable stress words in the same task, did not show a significant syllabic effect.

Stress and Syllabification

Previous reports have argued that English speakers do not segment speech into syllables. Cutler et al. (1986) found no syllabic effect in a syllable monitoring task with British English materials and subjects. Bradley et al. (1993) reported an overall advantage for CVC targets for both coda words and onset words with short vowels in a syllable monitoring task in Australian English, but did not interpret this as a syllabic effect. Cutler et al. (1986) also found that English speakers did not show any syllabic effects even when processing ‘‘easily syllabified’’ French materials. The conclusion reached by Cutler et al. (p. 397) is that ‘‘English speakers do not use syllabification even when the words they are listening to can be easily syllabified.’’ In what can be taken as a counter to this claim, our results provide evidence of a syllabic effect in English. There are at least three major differences between our experiments and those of Cutler et al. and Bradley et al. that might be responsible for this difference. First is our use of American English; it is logically possible that speakers of different dialects of English use different segmentation strategies. Second is the use of different methodologies: syllable monitoring in the Cutler et al. and Bradley et al. studies and an attentional-based phoneme monitoring task here; these two tasks might use different processes or representations. The third differ-

[4] In most previous experiments reporting syllabic effects (e.g., Mehler et al., 1981; Pallier et al., 1993) the critical interaction manifested itself as a crossover effect in the mean response times; some of our experiments do not show such a crossover. This is due to the presence of main effects (whether significant or not) and does not alter the interpretation of the basic (significant) interaction. When the interaction effect per se is calculated for the four cells in each experiment (i.e., with the main effects factored out) there is a symmetrical crossover effect, as there must be in any 2 by 2 design with a significant interaction (see, e.g., Rosnow & Rosenthal, 1995).

ence, and the one which we will now focus on, is the use of words with different stress patterns. Kahn (1980) has argued for a distinction in syllabification between words with first- and second-syllable stress, where the third phoneme in second-syllable stress onset words belongs only to the onset of the second syllable (''de-Bris''), while the third phoneme in first-syllable stress onset words with short vowels is ambisyllabic (''Bo[s]ton''), and thus not clearly associated with just one syllable. Our results with second-syllable stress words are consistent with the hypothesis that such words have a clear syllable boundary, as are the results reported by Allopenna (1995), in which a syllable-monitoring task using second-syllable stress words in American English produced an interaction between target syllable (CV vs CVC) and word structure (initial CV-CV vs CVC-CV) similar to that found by Mehler et al. (1981) with French.

At first glance, all of the experimental results involving first-syllable stress words are also consistent: neither our Experiment 5 nor Pallier (1994) showed any syllabic effect in the attentional phoneme monitoring task, and neither Cutler et al. (1986) nor Bradley et al. (1993) concluded that there were syllabic effects in English. However, Bradley et al.'s results with the syllable monitoring task (where there was an overall CVC advantage for words beginning with CVCV or CVCCV) do, as Bradley et al. note, admit of a syllabic explanation if ambisyllabicity creates an initial CVC syllable in words such as ''balance.'' The related findings of Allopenna (1995), in which multiple syllable monitoring experiments showed a CVC advantage in first-syllable stress words with short vowels, are consistent with the hypothesis that CVC syllabification occurs with these words. Such a CVC structure would also explain the lack of syllabic effects in the experiment of Pallier (1994) using first-syllable stress words, since even in the hypothesized onset induction condition the target would actually have been in the coda of the first syllable. The lack of a CVC effect in the experiments of Cutler et al. (1986) with British English subjects and materials then remains an anomaly, due perhaps to a dialect difference or one of the methodological differences discussed by Bradley et al. and Allopenna.

An alternative explanation (more consistent with the results and conclusions of Cutler et al., 1986) is that ambisyllabicity leads to an ''unclear'' syllable boundary, and that syllabic effects are detectable in English only when syllable boundaries are clear and unambiguous (e.g., with second-syllable stress words). This hypothesis requires that the faster RTs for CVC targets than for CV targets that were found by Bradley et al. (1993) and Allopenna (1995) be given an explanation that is not based on syllabic segmentation, e.g., that the additional information in a CVC syllable ensures a more reliable match (i.e., greater phonological overlap) between the target syllable and the word (Bradley et al., 1993). The hypothesis that syllabic segmentation occurs when syllable boundaries are clear (as in the experiments with French speakers and French materials of Mehler et al., 1981, and our results with American English speakers presented with second-syllable stress words) must be tempered by the results of Cutler et al. (1986) showing that English speakers do not syllabify French materials. Given these findings, the relation between segmentation and clarity of syllables is not a phenomenon based solely on acoustic cues. However, the other factors (e.g., phonological knowledge of one's language) involved have not as yet been decisively determined.

The data currently available do not clearly distinguish between these two possible interpretations. However, with either of these explanations, first-syllable stress words with long vowels should be clearly syllabified after the vowel and would thus be predicted to have the characteristics of onset words in the attentional monitoring task. We are currently testing this prediction.

Source of the Attentional Effect

An additional question of interest is the process by which attention was induced in these experiments. The experimental design did not follow that of typical attentional experiments in which a cue (neutral, valid, or invalid) precedes the decision stimulus; the subjects here did not distinguish between a ''cue'' (loosely, inductor) and a ''target.'' In our experiments, the construction of the onset and coda lists involved a majority of the words in a given list being of one structure; however, the lists were also constructed so that each target word was preceded by at least one inductor. The induction effect on a test word, then, could be due either to the presence of a single preceding word, or to a more global effect of the overall list. The results of the randomized experiment reported in the Discussion section of Experiment 3 bear on this issue; in these experimental lists there was no guarantee that test words would be directly preceded by an inductor word of corresponding structure (out of 114 words, there were 32 distractor words, as well as 16 target words of a different form). A significant interaction was nonetheless found, suggesting that syllabic induction occurs even when targets are not directly preceded by words of the same structure.

Further evidence in support of an effect of global attention comes from analysis of a control condition (briefly mentioned in Footnote 1) run in Experiments 1–4. In this condition, the 50 inductor words were evenly split between onset and coda words, leading to (presumably) lack of any global expectation for words of onset or coda form. The pseudorandom construction of the lists meant that an onset target could be preceded by either an onset or a coda inductor, and similarly for coda targets. The lists were of fixed order, so we performed a post-hoc analysis of the coda and onset targets, differentiated by the type of the preceding inductor (onset/coda).[5] Although there was a trend for targets to be responded to faster when preceded by an inductor of the same class, an analysis of variance with target type and type of preceding word as factors did not show a significant interaction ($F_1(1,9) = 1.60$, $p = .24$; $F_2(1,28) < 1$), arguing against the hypothesis that the syllabic effect obtained in Experiment 1 was due to induction solely from the preceding word. The interaction was also not significant in the control condition of Experiments 2, 3, or 4. Thus, there seems to be a global aspect of the attention induced in this paradigm which is not strictly due to the preceding item.

Speech Segmentation and Lexical Access

Although evidence from any experimental investigation of the segmentation capabilities of the human speech processing mechanism is interesting in its own right, the more important issue is the role of syllabic segmentation during lexical access in connected speech. Evidence of syllabic effects in on-line experimental tasks has typically been taken as support for the syllable as a unit of speech processing (e.g., Mehler et al., 1981). We have found evidence for syllabic segmentation; what does this say about lexical access in English?

Although subjects' RTs in our experiments (on the order of 600 ms from the onset of the target phoneme, which was about 200 ms from word beginning) certainly allow for the possibility that a post-lexical representation was used, the results of Experiment 4, in which a syllabic effect was found with pseudo-words, clearly showed that a lexical representation is not necessary for performance on this task. Since the instructions did not mention syllables, and isolated syllables never appeared in the experiment, the simplest (though not definitive) explanation is that we have tapped into a prelexical mechanism used in normal speech processing.

Our results are consistent with a hypothesis that syllabic segmentation occurs with English speakers and English materials when syllable boundaries are clear and unambiguous, and thus fit with a processing model in which the syllable is a unit of lexical access. However,

[5] Although the control lists were constructed with pseudo-random ordering, it should be noted that there is a confound of items with induction class in this analysis because of the fixed order of item presentation, i.e., each target word in the control conditions was always preceded by the same inductor word. This confound was not present in the analyses involving the main coda and onset induction conditions, since in this situation the induction type was a property of the entire list, not individual target items.

this does not explain how segmentation and lexical access occur in the cases where the phonological syllable boundaries are *not* clear.

An alternative way of interpreting our results is in terms of the Metrical Segmentation Strategy (MSS) of Cutler and Norris (1988). In this proposal, it is only strong syllables (those with an unreduced vowel, including all stressed syllables) that trigger segmentation and determine the boundaries for lexical access. In this proposal, the segmentation mechanism for English does not automatically segment speech into syllables (unlike the usual proposal for French), but rather strong syllable nuclei are recognized, and lexical access is done starting with some location preceding this point (e.g., the syllable onset). Evidence in support of this strategy comes both from patterns of speech misperception (Cutler and Butterfield, 1992), and from data involving the detection of words in bisyllabic nonwords (Cutler and Norris, 1988). Although our main concern has been with stress patterns rather than vowel quality, our finding of syllabic effects in second-syllable stress words, but not in first-syllable stress words, is fully consistent with the MSS, since the MSS would predict segmentation following the first syllable only in the second-syllable stress words. In addition, we have provided specific evidence that the syllable boundary preceding the strong syllable nucleus is precisely located by the speech perception system (something left somewhat underspecified by Cutler and Norris, 1988), and that knowledge of syllable onsets and codas is part of the segmentation process.

Nevertheless, various aspects of the syllabification of first-syllable stress words need to be investigated. Data from Allopenna (1995) and Bradley et al. (1993) are open to the interpretation that CVC syllabification occurs in first syllable stress words with short vowels, but this remains to be conclusively determined. In addition, phonological theory suggests that the syllabification may be clear in first syllable stress words with long vowels such as ‘‘cobra,’’ and a proposal that syllabification occurs in the processing of English when the boundary is clear would predict that the attentional paradigm would show an effect in this case. Such a result would be in conflict with the Metrical Segmentation Strategy as currently formulated.

Conclusion

In summary, using the attention directing paradigm of Pallier et al. (1993), we have shown that the speech processing system is sensitive to syllabic structure in English, at least for second-syllable stress words, and that this effect is not based on a post-lexical representation. Our results would seem to be incompatible with any processing theory that does not take syllables into account as psychologically real pre-lexical units of representation. Further work needs to define more precisely the circumstances under which such syllabic segmentation occurs in English and the relation of these tasks to normal speech processing.

Appendix

Stimulus Lists

In all of the stimulus lists, the phoneme which is the target for monitoring is capitalized within the word; targets for distractors are listed following the word.

Experiment 1: Second-Syllable Stress

Onset targets: chaBlis, deBris, fiBrosis, viBration, soPrano, dePression, dePloyment, neGlected, reGression, reGretful, seClude, deClare, deCrepit, soCratic, neCrosis, laCrosse.

Coda targets: suBdue, suBmerge, suBmission, suBsistence, hyPnosis, sePtember, baPtismal, maGnetic, coGnition, seGmental, suCcinct, teChnique, diCtation, suCcessive, noCturnal, vaCcine.

Onset inductors: deBrief, liBretto, viBrato, noBlesse, douBloon, luBricious, suPreme, caPrice, dePletion, rePly, dePraved, diPloma, dePlore, reProve, beGrudge, deGrade, deGree, diGression, miGration, reGroup, poGrom, seCretion, deCrease, deCline, reCruitment, reClaim, reDress, hyDraulic, beTray, beTrothed, reTreat, nuTrition, neuTrino, reStore, reSponse, diScuss, diSpute, diSperse, deSpise, caScade, reSpect, moSquito, geStation, reFrain, deFlate, deFraud, beFriend, nePHritis, deFlect, diFfract.

Coda inductors: suBmit, suBserve, suBtend, suBvert, suBside, suBject, sePtette, haPhazard, sePtillion, rhaPsodic, maGnesia, doGmatic, teCtonic, fiCtitious, suCceed, faCtitious, suCcess, daCtylic, maLformed, maLfunction, daLmation, paRtition, foRbid, peRfume, peRmit, feRment, peRcent, geRmane, foRsake, caRtoon, peRform, miSgive, diSjoint, diSrupt, miSvalue, miStake, coMbust, syMphonic, coMpound, syMbolic, coMbine, shaMpoo, laMpoon, coNvict, caNteen, coNsume, syNthetic, faNtastic, coNjoin, coNduct.

Onset distractors: suppression (G), distort (B), distinct (P), distiller (B), reprieve (N), bedraggled (S), betrayal (G), detritis (K), nutritious (P), patrician (K), bestir (G), patrol (M), chagrin (D), paprika (L), bestow (R), repress (F).

Coda distractors: magneto (B), concoct (P), confer (S), cantata (R), forsee (G), kurtosis (B), cosmetic (L), reptilian (K), narcotic (P), fortell (K), verbose (M), sulfuric (G), monsoon (K), harpoon (G), congest (R), bamboo (R).

Experiment 3

In Experiment 3, second-syllable stress onset targets without a medial cluster were substituted for the targets with clusters; five onset distractors were also replaced.

Onset: suBorn, deBate, hiBernal, toBacco, suPernal, dePosit, liPoma, laGoon, reGard, toGether, seCure, deCay, raCoon, psyCHosis, myCosis, loCale.

Distractors: vacation (B) (replaces distiller), record (N) (replaces reprieve), report (K) (replaces patrician), pagoda (D) (replaces chagrin), negate (F) (replaces repress).

Experiment 4

Experiment 4 used second-syllable stress pseudo-words as test words in both the onset and coda conditions, and also substituted pseudo-words for five distractors in each of the onset and coda sets.

Onset: faBlis, keBris, shiBrosis, siBration, foPrano, gePression, kePloyment, reGlected, leGression, leGretful, veClude, peClare, beCrepit, voCratic, teCrosis, baCrosse.

Coda: fuBdue, fuBmerge, vuBmission, guBsistence, myPnosis, vePtember, daPtismal, daGnetic, poGnition, feGmental, nuCcinct, beChnique, biCtation, vuCcessive, goCturnal, naCcine.

Onset distractors: gistort (B), detrayal (G), betritus (K), katrol (M), naprika (L).

Coda distractors: dagneto (B), gonfer (S), tosmetic (L), meptilian (K), lonsoon (K).

Experiment 5: First-Syllable stress

Coda test: giBson, suBject, suBterfuge, huBcap, baPtism, caPtain, gyPsy, ruPture, doGma, maGnet, piGment, coGnitive, taCtile, doCtor, faCtion, seCtor.

Onset test (long): coBra, viBraphone, cyPress, duPlex, miGraine, vaGrancy, miCrobe, seCret.

Onset test (short): faBric, goBlet, chaPlain, doPpler, juGgler, niGgling, reCluse, maCro.

Coda inductor: hoBnail, suBset, suBsidy, caPsize, caPtive, gyPsum, haPtic, naPkin, hyPnotize, rhaPsody, fiGment, ruGby, pyGmy, seGment, siGnal, siGma, diGnity, boXer (K), diCtate, peCtin, seCtion, toXin (K), veCtor, faCtory, kiDnap, voDka, kiDney, liTmus, beaTnik, fiLter, vuLgar, maLted, moLten, moRphine, tuRbine, keRnel, maRgin, jaRgon, noRmal, teMper, syMbol, buMper, raMpant, poMpous.

Onset inductor (long): heBrew, luBricant, hyBrid, fiBrous, feBrile, zeBra, rePlay, rePrint, cuProus, miGrate, tiGress, diGraph, reGress, vaGrant, cyClone, saCred, miCron, cyClist, hyDrate, maTrix, niTric, neuTral, paTriarch, reFlex, reFresh.

Onset inductor (short): suBlimate, taBlet, daBbler, puBlic, couPlet, saPling, diPloid, tiPpler, reProbate, caPricorn, neGligent, wiGgling, ticKlish, cyClic (short pronunciation), hecKler, bucKram, deCrement, maDrigal, maTtress, meTric, buTtress, cuStom, raScal, paStor, muFfler.

Coda distractors: magnum (B), signature (D), lecture (P), tactics (N), neptune (G), tipsy

(K), capsicum (L), sigmoid (B), victor (M), sultan (K), journal (T), halter (G), morbid (K), tamper (S), mandate (P), jetsam (R).

Onset distractors (long): cyclase (B), vibrate (K), rubric (M), libra (F), sucrose (D), cyclamate (B), hydrant (S), patron (G).

Onset distractors (short): goblin (R), sacral (P), segregate (P), leprous (T), saffron (P), petrel (G), basket (N), mustard (K).

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