The Phonetic Context of American English Flapping: Quantitative Evidence

David Eddington, Dirk Elzinga

Brigham Young University

Key words

American English

flapping

stress

syllabification

Abstract

The phonetic context in which word-medial flaps occur (in contrast to [t^h]) in American English is explored. The analysis focuses on stress placement, following phone, and syllabification. In Experiment 1, subjects provided their preference for [t^h] or [ɾ] in bisyllabic nonce words. Consistent with previous studies, flaps were preferred before stressless syllables and [t^h] before stressed syllables, but the following phone also exerted a small degree of influence. Experiments 2 and 3 tested whether [t^h] or [ɾ] are associated with a particular syllable position in bisyllabic words. They demonstrate that [t^h] is favored in onsets, while [ɾ] is not consistently placed in either the onset or coda, nor is it generally ambisyllabic. These findings contradict analyses that posit syllable division as a conditioning factor in the appearance of [t^h] versus [ɾ]. Experiment 4 examined the pronunciation of 480 multisyllabic words from the TIMIT corpus. ˈVCV was seen to favor [ɾ], while VˈCV favored [t^h]. In addition, flaps tend to be followed by syllabic sonorants and [t^h] by tense vowels. Because the following phones that influenced [t^h] and [ɾ] in Experiment 4 differ from those that were significant in Experiment 1, more research is necessary into the effect that following phones have on the appearance of [t^h] and [ɾ].

1 Introduction

The flap pronunciation of /d/ and /t/ is quite prevalent in dialects of North American English although it exists to varying degrees in other English dialects as well. The linguistic literature has treated various aspects of this phenomenon such as its possible phonetic origins (Silverman, 2004; Turk, 1992), how it varies according to sociolinguistic factors (Byrd, 1994; Strassel, 1998; Zue & Laferriere, 1979) as well as linguistic factors (Connine, 2004; Egido & Cooper, 1980; Gregory, Raymond, Bell,

Acknowledgments: We express our thanks to James Scobbie, William D. Raymond, and the anonymous reviewer for their suggestions and comments on this article.

Address for correspondence. David Eddington, Department of Linguistics and English Language, 4064 JFSB, Provo, UT 84602, USA; e-mail: <eddington@byu.edu>

Language and Speech 0023-8309; Vol 51(3): 245-266; 098542; DOI:10.1177/0023830908098542
http://las.sagepub.com

Fosler-Lussier, & Jurafsky, 1999; Laeufer, 1989; Nespor & Vogel, 1986; Patterson & Connine, 2001). Of particular interest to many researchers has been the exact phonetic context that conditions the flap variant of /t/ (Davis, 2003; de Jong, 1998; Harris, 1994; Kahn, 1980; Kiparsky, 1979; Parker & Walsh, 1982; Picard, 1984; Rhodes, 1994; Riehl, 2003; Selkirk, 1982; Steriade, 2000). Many different phonological contexts have been proposed for flapping and it would be of interest to find which is most accurate by comparing them with quantitative data from corpora and experiments. Unfortunately, any attempt at using quantitative data immediately runs into the problem of abstractness.

A linguistic entity may be considered abstract if it has no direct correlate in the acoustic speech signal or if it escapes verification by psycholinguistic experimentation. Voice onset time, for example, is not abstract because it is clearly measurable with spectrograph technology. Phonemes, on the other hand, are not apparent in the speech signal but psycholinguistic experimentation demonstrates that phoneme-like categories do exist (Jaeger, 1980). A variety of abstract mechanisms have been proposed in order to account for flapping, all of which assume that flaps are derived from underlying /t/.[1] For example, rule ordering is an integral part of several accounts (Jensen, 1993; Kahn, 1980; Kiparsky, 1979; Nespor & Vogel, 1986). Kahn (1980) and Selkirk (1982) assume resyllabification in the course of the derivation. The notion that syllables are organized into prosodic units called feet is central to flapping according to others (Davis, 2003; Giegerich, 1992; Kiparsky, 1979; Nespor & Vogel, 1986), while Harris's analysis (1994) makes use of phonological licensing.

Abstract features that serve as diacritic marks play a role in a number of analyses as well (Kahn, 1980; Kiparsky, 1979; Nespor & Vogel, 1986; Selkirk, 1982). For example, Kahn (1980) uses the feature [± consonantal] as a diacritic. Accordingly, when /t/ follows an /l/ that is [+cons], /t/ is realized as a stop (e.g., *altar* [ɑlt^{h}ɚ]). When /l/ is [-cons] /t/ is flapped (e.g., *altar* [ɑlɾɚ]). No actual phonetic difference between [-cons] and [+cons] laterals is cited, which suggests its use as a diacritic. All of these abstractions may have value within their respective theory-internal domain, but since they are not surface-observable, this makes it impossible to determine on empirical grounds which proposed context for flapping is more accurate.

The goal of the present study is to explore the phonetic context of word-internal flapping by considering observable entities, namely stress placement, following phone, and syllabification. First, we describe two corpus analyses and experiments designed to test the influence of stress and following vowel quality on word-internal flapping. In the following section, we discuss two experiments that test whether particular allophones (i.e., [t^h], [ɾ], [ʔ]) influence judgments of syllabification. We then provide empirical evidence that stress and vowel quality are major determinants of whether [t^h] or [ɾ] appear word-medially in American English.

[1] Coninne (2004), on the other hand, provides evidence that flaps are not derived from underlying /t/, but are stored as flaps in the mental lexicon.

2 Flapping: Stress and following vowel quality

Stress is commonly acknowledged as a conditioning factor in the flap versus stop alternation (Borowsky, 1991; Giegerich, 1992; Kahn, 1980; Ladefoged, 2006; Selkirk, 1972). It is generally agreed that flaps must be followed by unstressed vowels while [tʰ] precedes stressed vowels. However, stress and vowel reduction also interact in English. Since vowels commonly reduce in unstressed environments, a non-reduced vowel can be a potential cue for stress. Thus, certain vowels more commonly appear in stressed syllables and others in unstressed syllables. This suggests the possibility that flapping, at least word internally, may be related to particular vowels rather than, or in addition to, stress.

2.1 Corpus analysis

In order to compare stress and vowel quality as they relate to the distribution of [tʰ] and [ɾ] in American English we turned to the *CMU Pronouncing Dictionary* (n.d.) (CMUPD) which contains over 125,000 transcribed words including their stress pattern. From the CMUPD we searched for words with a medial /t/[2] that was followed by a vowel or syllabic sonorant, and that was preceded by a vowel or [ɹ]. This yields a context in which both [tʰ] and [ɾ] commonly appear. Syllabic [n] was not included since it is usually preceded by [ʔ] rather than [tʰ] or [ɾ], and we chose to narrow the study by focusing only on the contexts of [tʰ] and [ɾ]. We found 3114 words that fit these criteria. One unfortunate aspect of the CMUPD is that it does not transcribe flaps, which forced us to distinguish which words contained a flap and which ones contained an aspirated stop. Our decision was based on what both authors considered the most common pronunciation of the words in American English. Since the CMUPD includes information about stress we were able to compile the data in Table 1.

Table 1

Number of words in the *CMU Pronouncing Dictionary* with medial /t/ by stress and pronunciation

Stress before /t/	*Stress after /t/*	*[tʰ]*	*Example*	*[ɾ]*	*Example*
none	none	28	*Samaritan*	766	*marketable*
primary	none	6	*cortex*	1067	*article*
secondary	none	2	*attache*	644	*alligator*
none	primary	321	*cartoon*	0	–
none	secondary	219	*lunatic*	6	*Socrates*
primary	secondary	20	*satire*	19	*grotto*
secondary	primary	14	*eternal*	1	*whatever*
primary	primary	1	*pretax*	0	–

A pattern is clearly evident which supports what other researchers have described; flaps appear before unstressed syllables, while [tʰ] appears before syllables with either primary or secondary stress. These two generalizations account for 98% of these 3114 words in this phonetic context without specifying any other information.

The question we now ask is whether the appearance of [t^h] and [ɾ] is related to the phone that follows them. This information was obtained from the same 3114 word's from the CMUPD and appears in Table 2. Note that the CMUPD does not distinguish between [ə] and [ʌ], most likely because these are not distinct in most dialects of American English (Pullum & Ladusaw, 1986, p. 18). Instead, the symbol [ʌ] is often used to transcribe the stressed version of [ə], and since we are interested in the influence of following vowels and syllabic consonants apart from stress, a broad transcription that minimizes stress-conditioned allophony is desirable. The CMUPD also transcribes [ɨ] and [ɪ] with the same symbol in spite of their phonetic differences. Once again since [ɨ] is always stressless, this combination allows stress influences to be removed as much as possible from the analysis, although we recognize that completely divorcing stress from vowel quality is impossible given the close relationship between vowel quality and stress in English (e.g., Hammond, 1997).

Table 2

Number of words with word-medial /t/ in the *CMU Pronouncing Dictionary* by following phone and pronunciation

Vowel or syllabic sonorant after /t/	*[t^h]*	*Example*	*[ɾ]*	*Example*
ə	24	*gelatin*	846	*sonata*
ɪ	68	*hypnotism*	735	*analytical*
i	28	*amputee*	421	*abilities*
ɚ	19	*eternal*	350	*utterly*
l̩*	0	–	105	*portal*
ɛ	105	*hereditary*	1	*whatever*
ej	94	*attain*	1	*heartache*
ɔ	84	*auditory*	0	–
aj	64	*attired*	0	–
ɑ	38	*autopsy*	0	–
æ	26	*italic*	0	–
u	25	*solitude*	0	–
ow	32	*isotope*	42	*burrito*
ʊ	3	*overtook*	0	–
æw	1	*freetown*	0	–
ɔj	1	*rheumatoid*	1	*autoimmune*

* This was transcribed as a vowel followed by [l] in the CMUPD. We determined for each case whether the /l/ was syllabic or not in general American pronunciation.

2 In our view, allophones are not derived from underlying phonemes. Instead, we consider /t/ a category of sounds that are processed as instances of the same entity. The fact that so many disparate phones belong to this category is most likely due to the fact that they share orthographic representation.

The generalization that emerges is that flaps appear followed by [ə, ɪ, i, ɚ], and [l̩], while [tʰ] is most frequent preceding [ɛ, ej, ɔ, aj, ɑ, æ] and [u]. However, there is not enough data to determine how the vowels [ow, ʊ, æw], and [ɔj] pattern. By using the first two generalizations the following phones alone are able to correctly predict the appearance of [tʰ] and [ɾ] in 93% of the cases in comparison with stress that has a 98% success rate. Although we have tried to separate vowel quality and stress placement as much as possible in these analyses, it is not possible to completely disentangle them by mere inspection of the corpus. In addition, it is of interest to determine whether the generalizations about stress and phone quality are actually related to how speakers determine pronunciation as well. For this reason we carried out the following experiment.

2.2 Experiment 1

Rather than focus on the pronunciation of existing English words, whose pronunciation would be known, we used nonce words whose stress and following phone could be manipulated. The dependent variable was the subjects' preference of [tʰ] or [ɾ] in each nonce word. As independent variables in the present experiment we included stress (initial or final), and phone association. For the purposes of the study, flap-associated phones are those that the study of the CMUPD revealed most commonly follow [ɾ] (i.e., [ə, ɪ, i, ɚ, l̩]); stop-associated phones are those that are most closely related to a preceding [tʰ] (i.e., [ɛ, ej, aj, ɑ, æ]), and neutral-associated phones are not strongly associated with either [tʰ] or [ɾ] (i.e., [ʊ, æw, ɔj]). The phone association groups do not constitute what linguists would consider natural classes of sounds. For this reason, we also included a variable indicating whether the following phone was a syllabic sonorant, tense vowel, or lax vowel.

2.2.1 Test items

Three different nonce words were devised for each of the 13 vowel/syllabic sonorant phones tested (five stop-associated phones, five flap-associated phones, and three neutral-associated phones) for a total of 39 test items. All were bisyllabic words beginning and ending with a voiceless obstruent consonant (see Appendix A for a full listing). For example, [ʧ ___ ɛs] contains the phone [ɛ] that is related to preceding [tʰ], [gɪ ___ if] has [i] as the nucleus of the second syllable which is associated with a preceding [ɾ], and [kʰɪ ___ æw θ] contains [æw] that is not strongly associated with either [tʰ] or [ɾ].

2.2.2 Procedure

The test items were read to all of the subjects at the same time by a native American English speaker. Each test item was presented with initial stress and with final stress, although the order of presentation was randomized. The subjects' task was to choose which sounded more like a natural, native American English pronunciation to them. For example, consider [ʧə ___ ɛs]. On one presentation, the subjects heard A-[ʧətʰɛ́s] and B-[ʧəɾɛ́s] and marked either A or B as the most natural sounding of the two. Each of the two choices was repeated twice. On another presentation, which did not immediate precede or follow the first, the subjects heard A-[ʧə́tʰɛs] and B-[ʧə́ɾɛs] and marked either A or B as the most natural sounding of the two. In this way, each subject indicated 78 pronunciation preferences.

2.2.3 Subjects

Eighteen female and eight male undergraduate students participated in the study whose average age was 21. All were native speakers of American English.

2.2.4 Results and analysis

Logistic regression analysis was carried out using GoldVarb (Rand & Sankoff, 1990; Robinson, Lawrence, & Tagliamonte, 2001) in order to determine what factors influenced the subjects' choice of [t^h] or [ɾ] in the test words. In the first run of the analysis, we included phone association (stop-associated, flap-associated, neutral-associated), stress (initial syllable vs. final syllable), phone quality[3] (syllabic sonorant, tense vowel, lax vowel), the interaction between phone association and stress, and the interaction between phone quality and stress. This yielded the very parsimonious model described in Table 3 in which only the interaction between stress and phone association was found to be significant.

Table 3

Logistic regression results of Experiment 1. Positive weights indicate factors that favor a flap pronunciation

Variables	*Factor weight*	*Examples*
Flap-associated phone, initial stress	+.492	[ʧə́ _ l̩s]
Neutral-associated phone, initial stress	+.358	[kʰə́ _ ɔjf]
Stop-associated phone, initial stress	+.208	[də́ _ ejf]
Neutral-associated phone, final stress	–.300	[kʰɪ _ ǽwɵ]
Stop-associated phone, final stress	–.348	[ʧɪ _ ájk]
Flap-associated phone, final stress	–.404	[dɪ _ ɚ́ t]
Total $\chi^2 = 0.0005$, χ^2 per cell = 0.0001, Log likelihood = –1263.258		

The factor weights indicate the extent to which each combination of variables favors a flap pronunciation. Weights of +.100 and greater indicate factors that favor flaps, while weights of –.100 and lower indicate factors that disfavor flaps, and hence, favor [t^h]. Weights between +.100 and –.100 indicate no strong influence in either direction. Factor weights farther from zero indicate stronger influences than those closer to zero.[4]

---

3 Whether or not the [ɑ] that appeared in six of the test items was coded as lax or tense did not change the outcome of the analysis.

4 GoldVarb actually gives factor weights that vary between 1 and 0. These have been converted into a +1 to –1 scale for ease of interpretation.

Positive factor weights resulted for interaction factors containing initial stress and negative weights for final stress, which may suggest that stress alone is the influencing factor. To test this possibility we ran one analysis with stress alone and another with phone association alone. Phone association alone produced insignificant results while stress alone was significant (Total $\chi^2 = 0.0008$, χ^2 per cell = 0.0004, Log likelihood = –1273.079). The important question is whether stress alone produces a better fit to the data than the interaction between stress and phone association. This was done by comparing the log likelihoods of the stress-alone analysis and the analysis of the interaction between the two. This indicates that the interaction of stress and phone association produces a better fit to the data than stress by itself (χ^2 (2) =19.642, $p < 0.001$).[5] The insignificant results of the run with phone association alone, along with the data in Table 3, suggest that it plays a much smaller role than stress in the interaction analysis.

In summary, the phone associations resulting from the inspection of the CMUPD by themselves do not play a part the subjects' pronunciation preferences of the nonce words unless they are combined with stress. In contrast, stress patterns are significant by themselves, but provide a better fit to the data when combined with phone associations suggesting that stress is the more influential of the two variables. When taken together, the corpus analysis and Experiment 1 provide quantitative evidence for the factors that influence the appearance of [t^h] or [ɾ] word-medially. First, they corroborate previous studies that underscore the important role that stress plays in flapping. Flaps are generally, though not always, preferred when followed by stressless syllables, and [t^h] usually precede stressed syllables (see Table 1). The fact that the following phone is relevant in this alternation has not to our knowledge been previously tested.[6]

3 Flapping and syllabification

Many descriptions of the [t^h] versus [ɾ] alternation use differences in syllabification to predict whether [t^h] or [ɾ] appear in a particular word. While it is true that syllable boundaries are not part of the acoustic signal, which makes them more abstract in nature than stress placement or phone quality, extensive psycholinguistic experimentation clearly demonstrates that English speakers do have intuitions about where the boundaries fall (Derwing, 1992; Derwing & Neary, 1991; Fallows, 1981; Treiman, Bowey, & Bourassa, 2002; Treiman & Danis, 1988; Treiman, Gross, & Cwikiel-Glavin, 1992; Treiman, Staub, & Lavery, 1994; Treiman & Zukowski, 1990; Zamuner & Ohala, 1999).[7] However, in

5 This is done by doubling the absolute difference between the two log likelihoods where the degrees of freedom are the difference in degrees of freedom between the two runs. The degrees of freedom for each run are the number of values in each variable minus the number of variables (Chatterjee & Hadi, 2006, p. 324).

6 Scobbie (2005) reports a similar interplay between prosodic and segmental information in Scottish diphthong length alternations.

7 The fact that syllable boundaries are not manifest in the acoustic signal does not deny the possibility that some observable aspects of larger prosodic structures (e.g., pitch, amplitude, duration) may play a part in the organization of utterances into syllables without necessarily specifying where one syllable ends and the other begins. Thanks to James Scobbie for discussion of this point.

many instances there is a great deal of variability in speakers' intuitions regarding the placement of syllable boundaries, especially boundaries involving single intervocalic consonants.

Researchers have discussed a number of factors that may influence syllabification. The onset maximization principle states that a medial consonant belongs to the same syllable as the vowel which it precedes. When more than one consonant intervenes between vowels, they are also grouped together with the following vowel, subject to constraints on allowed sequences of consonants (Bailey, 1978; Hoard, 1971; Hooper, 1972; Kahn, 1980; Pulgram, 1970; Selkirk, 1982). Sonority plays a role in that syllable divisions should be made so that the last element of a syllable is more sonorous than the first element of the following syllable (Murray & Vennemann, 1983; Vennemann, 1988). A further principle influencing syllabification is legality. Consonant sequences allowed word-initially or word-finally guide the syllabification of word-medial clusters (Anderson & Jones, 1974; Martens, Daelemans, Gillis, & Taelman 2002; Steriade, 1999; Wells, 1990). Stress can also play a role in syllabification. There is a preference for stressed syllables in English to be heavy. This means that a stressed lax vowel should be followed by a consonant in the same syllable (Hammond, 1997; Wells, 1990). This can also be seen as an extension of the legality principle; since English words cannot end in a stressed lax vowel, syllables may not either.

Although syllables appear to be real for English speakers, the use of syllables in describing flapping is problematic in two ways. First, researchers do not agree on what part of the syllable flaps occur in. For example, Kenstowicz (1994), Selkirk (1982), and Wells (1982) assert that flapping occurs in syllable-final position. Giegerich (1992) on the other hand, contends that the context for flapping is syllable initial position, while according to Kahn (1980) and Gussenhoven (1986) flaps are always ambisyllabic.[8] Second, it appears that the sweeping claims about where a syllable boundary falls were made in these analyses without incorporating some kind of empirical evidence to support the hypothesized syllable boundary placement. Perhaps this explains why so many different models exist. Therefore, it is clear that more evidence is required regarding the relationship between flapping and syllabification, which is why we chose to carry out the following experiments.

It should be noted that these experiments are exploratory. That is, they were designed to explore what factors, (including the nature of the medial consonant), influence syllabification. If there is a consistent relationship between a particular syllabification and the appearance of [t^h] and [ɾ], that would indicate that syllable position is a significant factor in their distribution. Although the results will be compared to extant formal analyses of flapping, the experiments are not confirmatory in nature. That is, we did not propose particular phonetic contexts for the phones beforehand which we then attempted to confirm experimentally. For this reason, we

[8] For Kahn ambisyllabicity means that the consonant belongs to one syllable in the underlying representation and to another syllable one the surface.

did not begin with preconceived expectations about how subjects would respond that we could use to calculate a "success rate" for our analysis.

3.1
Experiment 2

Our data in this experiment are taken from a broader work on syllabification called the BYU Syllabification Study (BSS: Eddington, Treiman, Elzinga, forthcoming). In the BSS, 4990 bisyllabic English words were syllabified by an average of 22 people. This was accomplished by assigning each of the 841[9] test subjects one of 40 subsets of 125 test words to syllabify. In the online questionnaire, the test words were presented both orthographically and in a quasi-phonemic transcription.[10] For example, the word *photon* appeared in this manner:

photon

___ FOW / TAHN

___ FOWT / AHN

___ I'm not sure

The transcription was necessary given the sometimes tenuous relationship between English orthography and pronunciation (e.g., *castle* [kæsl], *walking* [wɑkʰɪ ŋ], *accute* [əkjut]). The subjects' task was to choose one of the syllabification options (e.g., either FOW / TAHN or FOWT / AHN) by clicking on a radio button that appeared next to each choice. It should be noted that this test paradigm allows us to determine whether the medial consonant is more likely to be the coda of the first syllable or the onset of the second by requiring subjects to divide the word, thus forcing the consonant into one syllable or the other. The option of ambisyllabicity, putting the consonant in both syllables, was not include as a possibility.

We extracted 223 test items from the BSS with a medial /t/ that are preceded by a vowel and are followed by a vowel or a syllabic sonorant (e.g., *attend*, *button*, *netting*, *atom*, *brutal*). Some words were not selected for the analysis due to their low frequency (e.g., *putee*, *utile*, *zloty*). The 223 items that were considered are listed in Appendix B. Before performing the statistical analyses we eliminated all 23 *I'm not sure* responses from consideration, which only constituted 0.46% of the 4938 responses to these items. The purpose of the study was to measure syllabification preferences, therefore, if a subject was unsure of how to divide a word, that gives little useful information to draw conclusions from.

9 Twenty-five subjects syllabified two different test sets.

10 Transcription of the test words was based on an expanded version of the Hoosier Mental Lexicon (Pisoni, Nusbaum, Luce, & Slowiaczek, 1985) although the ARPAbet alphabet was used in the test items.

3.1.1 Results and discussion

The goal of the analysis is to determine what factors influenced the subjects' choice of syllabification, but most importantly, whether particular pronunciations of /t/ are a factor in syllabification. For each of the 223 items we determined what the normative pronunciation of /t/ is in American English. Both of the authors' pronunciation intuitions concurred in all of the cases. Three pronunciations were evident: [tʰ], [ʔ], and [ɾ]. At this point it would be tempting to simply count how many responses placed each phone in the syllable coda or onset and form our conclusions from those data. However, many other factors influence syllabification and they must be taken into account when performing the statistical analysis. Based on factors discussed in previous studies, we included a number of factors as independent variables:

(1) Phone: the general pronunciation of /t/ ([tʰ], [ʔ], or [ɾ]).

(2) Vowel quality: whether the vowel preceding /t/ is tense or lax.

(3) Geminate: whether /t/ is spelled with a geminate consonant or not.

(4) Morpheme boundary: if the word is monomorphemic, or if not, whether a morpheme boundary precedes or follows /t/.

(5) Stress: whether primary stress falls on the first syllable or not.

We also included some interaction factors by combining variables 1 and 2, 1 and 5, and 2 and 5 into separate factor groups. The dependent variable was choice of syllabification. V.CV responses are exemplified by syllabifying *photon* as FOW / TAHN, while FOWT / AHN illustrates VC.V responses. In this study we include the quality of the preceding vowel because it has been shown to affect syllabification. This contrasts with our interest in following vowel quality in the previous section where the focus was on pronunciation of /t/ rather than syllabification.

Logistic regression analysis was carried out on the data using GoldVarb (Rand & Sankoff, 1990; Robinson, Lawrence, & Tagliamonte, 2001). Logistic regression is well suited to the task since it allows nominal variables as well as variables with unequal numbers of items in each category. The initial analysis using the stepping up and down method yielded a very parsimonious fit for the data in which only two variables were calculated as significant: morpheme boundaries, and the interaction group comprised of preceding vowel quality and the pronunciation of /t/.

The analysis reported in Table 4 shows the extent to which each factor favors V.CV syllabification. Weights of +.100 and greater indicate factors that favor V.CV syllabification. Weights of –.100 and lower indicate factors that disfavor V.CV syllabification, meaning that they favor VC.V. Weights between +.100 and –.100 do not show a strong pull in either direction.

According to the analysis, stress, geminate spelling, vowel quality, and medial phone alone do not contribute significantly to the syllabification preferences of the test subjects to the 223 test items. However, it does demonstrate an effect of morpheme

Table 4

Logistic regression results from Experiment 2. Positive weights indicate factors that favor V.CV syllabifications

			V.CV	*No of words per category*
Morpheme boundary (#)				
V#CV			+.150	4
monomorphemic			+.078	166
VC#V			–.230	55
Preceding vowel quality by phone				
tense	+	[tʰ]	+.750	29
lax	+	[tʰ]	+.550	9
tense	+	[ɾ]	+.088	48
tense	+	[ʔ]	–.028	12
lax	+	[ɾ]	–.302	109
lax	+	[ʔ]	–.358	18

$p < 0.000$; Total $\chi^2 = 8.8344$; χ^2 per cell = 0.5890; Log likelihood = –2331.051

boundaries; people tend to make syllable boundaries coincide with morpheme boundaries when they exist in a word. An even stronger influence is exerted by the combination of preceding vowel quality and the word-medial consonant allophone; words pronounced with medial [tʰ] strongly favored placement of [tʰ] in the syllable onset. Words with [ɾ] and [ʔ], on the other hand, are more complex. When preceded by a lax vowel [ɾ] and [ʔ] tend to be placed in the coda. However, when the vowel is tense the influence of [ɾ] and [ʔ] on syllabification is negligible.

For the purposes of the present study, the influence that flaps have on syllabification preferences is the most important factor. It is clear that no single syllabification (either V.CV or VC.V) is favored by the appearance of a flap as the medial allophone. Instead, their syllabic positioning is highly dependent on the quality of the preceding vowel. This contrasts with Kenstowicz (1994), Selkirk (1982), and Wells (1982) who assert that all flaps appear in the syllable coda. In like manner it contradicts Giegerich's (1992) stance that all flaps occur in the syllable onset. Moreover, the interaction between flapping and preceding vowel quality is a state of affairs that is not specifically predicted by any extant analysis of flapping.

At this point, it should be apparent that there are two weaknesses in this experimental paradigm. The first is that the experiment was conducted in written form. The subjects did not hear the test words nor the different syllabification options. What is more, the quasi-phonemic representation used in the responses showed [tʰ], [ɾ], and [ʔ] as orthographic *T*. Our assumption is that the pronunciation of the words would influence the subjects' choice even though they responded to visual stimuli. The second weakness is that the responses did not include an ambisyllabic option. For instance, the choices for *atom* were A/TUHM, AT/UHM, and "I'm not sure."

AT/TUHM was not an option. In order to address these issues and provide further evidence we carried out Experiment 3.

3.2 Experiment 3

3.2.1 Stimuli

A total of 63 test words were used (see Appendix C). All were bisyllabic words containing a single medial consonant which was not written with a geminate grapheme. Each test item was stressed on the first syllable. Given the influence of morpheme boundaries measured in Experiment 2, we controlled for this variable by limiting the test items to monomorphemic words. We avoided words with [ɑ] as the nucleus of the first syllable since this vowel's status as lax or tense is not always clear. For example, both Wells (1982) and Ladefoged (2006) refer to [ɑ_t] as tense, since it can occur in an open syllable — a standard diagnostic for this distinction in English. However, Halle and Mohanan (1985) and Hammond (1997) recognize two vowels: [ɑ], a low back lax vowel and [ɑ_t], a low back tense vowel, based on other distributional properties which distinguish tense and lax vowels. No test items were chosen containing a medial /d/ since this may flap as well and we wanted to avoid this unwanted influence when studying flapping of /t/.

Based on the findings of Experiment 2, we included quality of the preceding vowel (tense or lax) as a variable. The other variable was type of medial consonant, which was either [ɾ],[11] [tʰ], other sonorant ([m, n, l, ɹ]), or other stop/affricate ([k, p, b, g, ʤ]). This yields a two by four experimental design with nine test items in each cell. Unfortunately, besides *satire* we were unable to find other words fitting the criteria that have a lax vowel and are generally pronounced [tʰ] in American English. This accounts for the 63 rather than the expected 72 items in a two by four design with nine items per cell. The dependent variable was whether the medial consonant was placed in the coda of the first syllable, the onset of the second, or in both.

3.2.2 Design and procedure

Our methodology in this study follows that of Treiman et al. (2002) quite closely. Subjects heard these instructions for one part of the experiment:

> I'm going to say a word and I want you to repeat back to me what sounds to you like the first part of the word. For example, if I say *without* you might say *with*. If I say *redo* you might say *re*. So, for practice what is the first part of *heavy*? How about *attack*? There really is no correct or incorrect answer, just whatever sounds best to you. There are 63 words so it won't take long. Let's start.

So, when the subject heard *focus* [foʷkʰəs], for example, he or she would give a verbal response: [foʷ] or [foʷk]. Occasionally responses that did not divide words syllabically were given such as [f]. These responses were not included in the analysis.

---

[11] We determined the pronunciation of /t/ in the test words as [ɾ]or [th] based on what we felt was a general American pronunciation.

The experimenter recorded the response by circling either *fo*, *foc*, or *other* on a specially designed response sheet.

The second part of the experiment asked the subjects to identify the last part of each word rather than the first and similar instructions were given. The most common responses to *focus* were [kʰəs] and [əs]. The order in which the test items were presented was randomized on each test as was which of the two parts of the test was presented first. All subjects responded to the same recordings containing the instructions and presentation of the test items. In this paradigm, the subjects responded to auditory stimuli and were not given any visual representation of the test words. In addition, ambisyllabic responses were possible as when a subject gave the first part of *focus* as [foʷk] and the last part as [kʰəs]. The use of auditory stimuli and the possibility of ambisyllabic responses address the drawbacks inherent in the methodology of Experiment 2.

3.2.3 Subjects

Nineteen native English-speaking students who were enrolled in a college-level foreign language course participated in the experiment: 11 women and eight men. Fifteen were between 20 and 24 years old and four were 26 or older.

3.2.4 Results

We compared each subject's responses to both parts of the test and determined whether they placed the medial consonant for each test item in the coda *(gen)(ie)*, the onset *(ge)(nie)*, in both *(ge(n)ie)* or in neither *(ge)n(ie)*. Other responses such as *(g)(enie)* were not included in the analysis. In Experiment 1, the dependent variable was a binary choice between a V.CV and VC.V syllabification. This means that the results of a V.CV analysis would be the mirror image of the results of a VC.V analysis. However, in Experiment 2 four response types were possible which necessitated four different statistical analyses (Table 5). This means that the analysis that determines what factors influence VC.V responses pits those responses against the other three response types combined (i.e., V.CV, ambisyllabic, and neither syllable). For this reason, particular vowel and consonant combinations are sometimes calculated to favor more than one response type. For instance, test items with lax vowels in the first syllable followed by obstruents are calculated to highly favor VC.V syllabification in the VC.V analysis, to favor ambisyllabic responses in the ambisyllabic analysis, to slightly favor placement into neither syllable in the neither syllable analysis, and to disfavor a V.CV syllabification in the V.CV analysis. In all four analyses, the only factor group that was observed to be significant was the quality of the vowel in the first syllable combined with the type of medial consonant.

In logistic regression, cells containing zeros are not allowed and prevent an analysis from running. These zero cells or knockouts indicate that a factor value either always or never occurs with a particular dependent variable. One knockout occurred in our data during the VC.V run, namely, no cases of [tʰ] were placed in the syllable coda. We indicate this categorical influence in Table 5 with a factor weight of zero. In order to calculate the weights of the remaining factor groups all cases of

Table 5

Logistic regression results from Experiment 3. Positive weights indicate factors that favor each syllabification

	VC.V	*V.CV*	*Ambisyllabic*	*Neither syllable*
Vowel quality by consonant type				
Lax + obstruent	+.452	–.318	+.356	+.114
Lax + sonorant	+.754	–.582	+.474	–.020
Lax + [ɾ]	+.324	–.284	+.100	+.290
Tense + obstruent	–.812	+.258	–.144	–.034
Tense + sonorant	–.180	+.060	+.066	+.020
Tense + [t^h]	.000	+.538	–.510	–.282
Tense + [ɾ]	–.378	+.276	–.272	–.074

VC.V: Total χ^2 = 0.0000, χ^2 per cell = 0.0000, Log likelihood = –256.680
V.CV: Total χ^2 = 0.0004, χ^2 per cell = 0.0001, Log likelihood = –670.446
Ambisyllabic: Total χ^2 = 0.0000, χ^2 per cell = 0.0000, Log likelihood = –344.996
Neither syllable: Total χ^2 = 0.0002, χ^2 per cell = .0000, Log likelihood = –559.421

[t^h] were removed and the analysis rerun. In the other three analyses, VC.V responses were combined with other response types which eliminated this knockout.

3.2.5 Discussion

The general tendency observed in other studies of syllabification is borne out here as well: lax vowels tend to attract consonants into the coda of their syllable, while tense vowels tend to repel following consonants into the onset of the second syllable. Ambisyllabic responses and responses that placed the consonant in neither syllable cooccur in two factor groups. This leads us to believe that cases in which theoretical accounts consider a consonant to belong to both syllables could instead be considered uncertainty on the part of the speakers as to which syllable the consonant belongs. Further research would be needed to in order to separate these two possibilities.

The crucial question we sought to answer with this experiment is what role medial consonants have in determining syllable boundaries. It is clear that [t^h] favors syllabification that places it in the syllable onset. However, the placement of the flap is much less categorical. The syllabification of flaps differs little from that of other consonants; when preceded by lax vowels, flaps, as well as other obstruents and sonorants, tend to fall into the syllable coda. When preceded by a tense vowel, flaps, [t^h], and other obstruents, are generally placed in the onset of the second syllable. Once again, flaps do not consistently favor appearing in the coda or the onset, nor do they consistently favor ambisyllabicity; therefore, analyses that distinguish between flapping and non-flapping contexts based on syllable position (Giegerich, 1992; Gussenhoven, 1986; Kahn, 1980; Kenstowicz, 1994; Selkirk, 1982; Wells, 1982) are again not supported.

4 The flapping environment without the syllable

If syllabification fails to distinguish the environments in which [ɾ] appears, is there some other way to account for their distribution of [tʰ] and [ɾ] based on measurable factors? The corpus data and the results of Experiment 1 suggest that stress and following phone association are factors, but that study has two drawbacks. First, it is contains only 223 test items. Second, the pronunciation of /t/ was given as what we felt was the most common pronunciation in American English, rather than on naturally occurring variation between and within [tʰ] and [ɾ].

In order to provide more compelling evidence we turned to a database of 3719 instances of /t/ (Eddington, 2007), which were extracted from the TIMIT corpus (Garofolo, Lamel, Fisher, Fiscus, Pallett, & Dahlgren, 1993; Zue & Seneff, 1996). TIMIT consists of a total of 6300 utterances (2342 different sentences) which were obtained by asking 630 American English speakers to read 10 sentences each. Each utterance is transcribed phonetically. From the subset of 3719, we found 480 instances of [tʰ] and [ɾ] that appear word-internally, are preceded by a vowel, and are followed by a vowel or syllabic sonorant. This yielded 349 flaps[12] and 131 instances of [tʰ]. In contrast to the test items in Experiments 1 and 2, the words for the present experiment were not all bisyllabic, and unlike the dictionary corpus, not every word in this database is unique. This means that the data set contains the kinds of variation in pronunciation that is characteristic of more natural speech. For example, it contains instances of *reality* pronounced with both [tʰ] and [ɾ].

Experiment 4 differs from Experiments 2 and 3 in a crucial way. In the latter two, the dependent variable was the subject's choice of syllabification. We included independent variables such as stress, preceding vowel quality, and morpheme boundary because previous research suggested these to be relevant factors in syllabification. For our purposes, the most crucial thing to test was whether [tʰ] or [ɾ] favored one syllabification over another. In Experiment 4, on the other hand, the dependent variable is the pronunciation of /t/ as [tʰ] or [ɾ]. Therefore, the independent variables were chosen that are thought to relate to pronunciation of /t/ rather than syllabification.

We submitted these items to a logistic regression analysis with the following independent variables:

(1) The stress of the preceding vowel (stressless versus primary stress or secondary stress combined).

(2) The stress of the following vowel (stressless versus primary stress or secondary stress combined).

(3) The quality of the phone following /t/ (syllabic sonorant, tense vowel, lax vowel[13]).

(4) The phone association of the following phone (see Experiment 1).

---

[12] The closure duration of 17 of these items was long enough that TIMIT transcribes them as [d], whereas we coded them as flaps.

[13] The six instances of [ɑ] were coded as lax vowels.

The analysis revealed that only variables 1–3 were significant suggesting that these factors delineate the phonetic environments that allow [tʰ] and [ɾ] to be distinguished without invoking the syllable. In Table 6, positive weights favor [ɾ] and negative weights favor [tʰ]. Consistent with the findings of other researchers, flaps generally occur between a stressed and stressless syllable and tend to occur preceding syllabic sonorants. The aspirated stop favors appearing between a stressless and stressed syllable and tends to be followed by tense vowels.

Table 6

Logistic regression results from Experiment 4. Positive weights favor the appearance of [ɾ] word-internally

Preceding syllable	
Stressed	+.306
Stressless	–.418
Following phone	
Lax vowel	+.046
Tense vowel	–.394
Syllabic sonorant	+.372
Following syllable	
Stressed	–.896
Stressless	+.384

$p < 0.000$, Total $\chi^2 = 4.9370$, χ^2 per cell = 0.4114, Log likelihood = –133.831

These findings contradict those of Experiment 1 in one regard. While stress is an important factor in both experiments, in the present experiment the following phone (tense vowel, lax vowel, syllabic sonorant) was calculated to be a factor while phone association (phones associated with preceding flaps, stops, or neither) was not. Just the opposite was found in Experiment 1. Perhaps this is due to differences in stimuli or experimental design. Experiment 1 elicited preferred pronunciations in nonce words, while Experiment 4 looks at possible influencing factors on the pronunciation of extant words extracted from spoken sentences. This issue merits further attention in future studies.

5 Conclusions

Does prosodic structure condition the word-medial realization of /t/ as either [tʰ] or [ɾ]? On the one hand, our evidence confirms the large body of evidence that points to the crucial role of stress on the appearance of these phones. If the flap consistently fell into one part of the syllable while [tʰ] fell into another, a strong case could be made for the role of syllable boundary in this distribution as well. However, the evidence we have adduced suggests otherwise. Test subjects in Experiments 2 and 3 placed the aspirated stop syllable-initially to a highly significant degree, yet, flaps appeared in both the onset and the coda depending on the quality of the nucleus of the first syllable of the word (i.e., tense or lax). The test subjects also demonstrated a great deal of insecurity about which syllable flaps belong to judging by their tendency to assign flaps to both syllables or to neither in Experiment 3. Therefore, it is safe to conclude that the position of the phone in the syllable cannot be considered the crucial environment that conditions the production of flap allophones in American English.

Experiments 1 and 4 provide strong supporting evidence for previous analyses that present stress as a major influencing factor in the appearance of [t^h] or [ɾ] word-medially. Flaps generally appear followed by stressless syllables and [t^h] precedes stressed syllables. However, our evidence suggests that the phone that follows /t/ also influences the realization, although to a smaller degree. In Experiment 1, the following phones that favored [t^h] or [ɾ] were those that most often followed [t^h] or [ɾ] in the CMUPD. We called these groups phone associations. In Experiment 4, on the contrary, phone associations were not significant, but rather, whether the following phone was a tense vowel, lax vowel, or syllabic sonorant. The reason for this discrepancy is unclear and more research is needed to more accurately determine how the following phone interacts with stress to produce phonetic contexts that favor either [t^h] or [ɾ].

References

ANDERSON, J. M., & JONES, C. (1974). Three theses concerning phonological representations. *Journal of Linguistics*, **10**, 1–26.

BAILEY, C.-J. N. (1978). *Gradience in English syllabization and a revised concept of unmarked syllabization*. Bloomington, IN: Indiana University Linguistics Club.

BOROWSKY, T. (1991). *Topics in the lexical phonology of English*. New York: Garland Press.

BYRD, D. (1994). Relations of sex and dialect to reduction. *Speech Communication*, **15**, 39–54.

CHATTERJEE, S., & HADI, A. S. (2006). *Regression analysis by example*. Hoboken, NJ: Wiley Interscience.

CMU Pronouncing Dictionary. (n.d.) Retrieved October 6, 2008 from http://www.speech.cs.cmu.edu/cgi-bin/cmudict

CONNINE, C. M. (2004). It's not what you hear but how often you hear it: On the neglected role of phonological variant frequency in auditory word recognition. *Psychonomic Bulletin and Review*, **11**, 1084–1089.

DAVIS, S. (2003). Capitalistic vs. militaristic: The paradigm uniformity effect reconsidered. In L. J. Downing, T. A. Hall, & R. Raffelsiefen (Eds.), *Paradigms in phonological theory* (pp. 107–121). Oxford: Oxford University Press.

De JONG, K. (1998). Stress-related variation in the articulation of coda alveolar stops: Flapping revisited. *Journal of Phonetics*, **26**, 283–310.

DERWING, B. L. (1992). A 'pause-break' task for eliciting syllable boundary judgments from literate and illiterate speakers: Preliminary results for five diverse languages. *Language and Speech*, **35**, 219–235.

DERWING, B. L., & NEARY, T. M. (1991). The 'vowel-stickiness' phenomenon: Three experimental sources of evidence. *Proceedings of the 12th International Congress of Phonetic Sciences*, **3**, 210–213.

EDDINGTON, D. (2007). Flaps and other variants of /t/ in American English: Allophonic distribution without constraints, rules, or abstractions. *Cognitive Linguistics*, **18**, 23–46.

EDDINGTON, D., TREIMAN, R., ELZINGA, D. (forthcoming). *The syllabification of American English*. Unpublished manuscript, Brigham Young University.

EGIDO, C., & COOPER, W. E. (1980). Blocking of alveolar flapping in speech production: The role of syntactic boundaries and deletion sites. *Journal of Phonetics*, **8**, 175–184.

FALLOWS, D. (1981). Experimental evidence for English syllabification and syllable structure. *Journal of Linguistics*, **17**, 309–317.

GAROFOLO, J. S., LAMEL, L. F., FISHER, W. M., FISCUS, J. G., PALLETT, D. S., & DAHLGREN, N. L. (1993). *DARPA TIMIT: Acoustic-phonetic continuous speech corpus*. Philadelphia, PA: Linguistic Data Consortium.

GIEGERICH, H. J. (1992). *English phonology: An introduction*. Cambridge: Cambridge University Press.

GREGORY, M. L., RAYMOND, W. D., BELL, A., FOSLER-LUSSIER, E., & JURAFSKY, D. (1999). The effects of collocational strength and contextual predictability in lexical production. *Chicago Linguistic Society*, **35**, 151–166.

GUSSENHOVEN, C. (1986). English plosive allophone and ambisyllabicity. *Gramma*, **10**, 119–141.

HALLE, M., & MOHANAN, K. P. (1985). Segmental phonology of Modern English. *Linguistic Inquiry*, **16**, 57–116.

HAMMOND, M. (1997). Vowel quantity and syllabification in English. *Language*, **73**, 1–17.

HARRIS, J. (1994). *English sound structure*. Oxford: Blackwell.

HOARD, J. E. (1971). Aspiration, tenseness, and syllabification in English. *Language*, **47**, 133–140.

HOOPER, J. B. (1972). The syllable in phonological theory. *Language*, **48**, 525–540.

JAEGER, J. J. (1980). Testing the psychological reality of phonemes. *Language and Speech*, **23**, 233–253.

JENSEN, J. T. (1993). *English phonology*. Amsterdam: John Benjamins.

KAHN, D. (1980). *Syllable-based generalizations in English phonology*. New York: Garland.

KENSTOWICZ, M. (1994). *Phonology in generative grammar*. Cambridge, MA: Blackwell.

KIPARSKY, P. (1979). Metrical structure assignment is cyclic. *Linguistic Inquiry*, **10**, 421–441.

LADEFOGED, P. (2006). *A course in phonetics* (5th ed.). Boston: Thomson Wadsworth.

LAEUFER, C. (1989). French linking, English flapping, and the relation between syntax and phonology. In C. Kirschner & J. Decesaris (Eds.), *Studies in romance linguistics* (pp. 225–247). Amsterdam: John Benjamins.

MARTENS, E., DAELEMANS, W., GILLIS, S., & TAELMAN, H. (2002). Where do syllables come from? In W. Gray & C. Schunn (Eds.), *Proceedings of the Twenty-Fourth Annual Conference of the Cognitive Science Society* (pp. 657–664). Fairfax, VA: George Mason University.

MURRAY, R., & VENNEMANN, T. (1983). Sound change and syllable structure in Germanic phonology. *Language*, **59**, 514–528.

NESPOR, M., & VOGEL, I. (1986). *Prosodic phonology*. Dordrecht: Foris.

PARKER, F., & WALSH. T. (1982). Blocking of alveolar flapping: A linguistic analysis. *Journal of Phonetics*, **10**, 301–314.

PATTERSON, D., & CONNINE, C. M. (2001). A corpus analysis of variant frequency in American English flap production. *Phonetica*, **58**, 254–275.

PICARD, M. (1984). English aspiration and flapping revisited. *Canadian Journal of Linguistics*, **29**, 42–57.

PISONI, D. B., NUSBAUM, H. C., LUCE, P. A., & SLOWIACZEK, L. M. (1985). Speech perception, word recognition, and the structure of the lexicon. *Speech Communication*, **4**, 75–95.

PULGRAM, E. (1970). *Syllable, word, nexus, cursus*. The Hague: Mouton.

PULLUM, G. K., & LADUSAW, W. A. (1986). *Phonetic symbol guide*. Chicago: University of Chicago Press.

RAND, D., & SANKOFF, D. (1990). *GoldVarb: A variable rule application for MacIntosh*. Montréal: Centre de recherches mathématiques, Université de Montréal.

RHODES, R. A. (1994). Flapping in American English. In W. U. Dressler, M. Prinzhorn, & J. R. Dennison (Eds.), *Proceedings of the 7th International Phonology Meeting* (pp. 217–232). Torino: Rosenburg and Sellier.

RIEHL, A. K. (2003). American English flapping: Perceptual and acoustic evidence against paradigm uniformity with phonetic features. *Working Papers of the Cornell Phonetics Laboratory*, **15**, 271–337.

ROBINSON, J., LAWRENCE, H., & TAGLIAMONTE, S. (2001). *GoldVarb 2001: A multivariate analysis application for Windows*. Retrieved May 23, 2007 from www.york.ac.uk/depts/lang/webstuff/goldvarb

SCOBBIE, J. M. (2005). *The 'end' of phonology: The theoretical significance of interface phenomena*. Paper presented at the First International Conference on the Linguistics of Contemporary English, Edinburgh, Scotland.

SELKIRK, E. (1972). *The phrase phonology of English and French*. PhD dissertation, Massachusetts Institute of Techonolgy.

SELKIRK, E. (1982). The syllable. In H. van der Hulst, & N. Smith (Eds.), *The structure of phonological representations part II* (pp. 337–383). Dordrecht: Foris.

SILVERMAN, D. (2004). On the phonetic and cognitive nature of alveolar stop allophony in American English. *Cognitive Linguistics*, **15**, 69–93.

STERIADE, D. (1999). Alternatives to syllable-based accounts of consonantal phonotactics. In O. Fujimura, B. Joseph, & B. Palek (Eds.), *Proceedings of the 1998 Linguistics and Phonetics Conference* (pp. 205–242). Prague: The Karolinum Press.

STERIADE, D. (2000). Paradigm uniformity and the phonetics–phonology boundary. In M. Broe, & J. Pierrehumbert (Eds.), *Papers in laboratory phonology 5* (pp. 313–334).

STRASSEL, S. (1998). Variation in American English flapping. In C. Paradis, D. Vincent, D. Deshaies, & M. Laforest (Eds.), *Papers in sociolinguistics: NWAV-26 à l'Université Laval* (pp. 125–135). Quebec: Nota Bene.

TREIMAN, R., BOWEY, J. A., & BOURASSA, D. (2002). Segmentation of spoken words into syllables by English-speaking children. *Journal of Experimental Child Psychology*, **83**, 213–238.

TREIMAN, R., & DANIS, C. (1988). Syllabification of intervocalic consonants. *Journal of Memory and Language*, **27**, 87–104.

TREIMAN, R., GROSS, J., & CWIKIEL-GLAVIN, A. (1992). The syllabification of /s/ clusters in English. *Journal of Phonetics*, **20**, 383–402.

TREIMAN, R., STAUB, K., & LAVERY, P. (1994). Syllabification of bisyllabic nonwords: Evidence from short-term memory. *Language and Speech*, **37**, 45–60.

TREIMAN, R., & ZUKOWSKI, A. (1990). Toward an understanding of English syllabification. *Journal of Memory and Language*, **29**, 66–85.

TURK, A. (1992). The American English flapping rule and the effect of stress on stop consonant durations. *Working Papers of the Cornell Phonetics Laboratory*, **7**, 103–133.

VENNEMANN, T. (1988). *Preference laws for syllable structure and the explanation of sound change* in Mouton de Gruyter.

WELLS, J. C. (1982). *Accents of English* (Vol. **1**). Cambridge: Cambridge University Press.

WELLS, J. C. (1990). Syllabification and allophony. In S. Ramsaran (Ed.), *Studies in the pronunciation of English: A commemorative volume in honor of A. C. Gimson* (pp. 76–86). London and New York: Routledge.

ZAMUNER, T. S., & OHALA, D. K. (1999). Preliterate children's syllabification of intervocalic consonants. In A. Greenhill, H. Littlefield, & C. Tano (Eds.), *Proceedings of the 23rd Annual*

Boston Conference on Language Development (pp. 753–763). Somerville MA: Cascadilla Press.

ZUE, V. W., & LAFERRIERE, M. (1979). Acoustic study of medial /t, d/ in American English. *Journal of the Acoustic Society of America*, **66**, 1038–1050.

ZUE, V., & SENEFF, S. (1996). Transcription and alignment of the TIMIT database. In H. Fujisaki (Ed.), *Recent research toward advanced man–machine interface through spoken language* (pp. 464–447). Amsterdam: Elsevier.

Appendix A: Test words for Experiment 1

Phones associated with [ɾ]	*Phones associated with [tʰ]*	*Phones associated with neither*
([ɪ, ə, i, ɚ, l̩])	([ɛ, aj, ej, æ,ɑ])	([æw, ɔj, ʊ])
ʧə _ l̩s	ʧə _ ɛs	kʰə _ ɔjf
vɪ _ ɚs	vɪ _ ajs	pʰɪ _ æwk
də _ if	də _ ejf	ʧə _ ʊs
zə _ əʃ	zə _ æʃ	bɪ _ ɔjk
dɪ _ Iθ	dɪ _ ɑθ	də _ æwp
ʧɪ _ l̩k	ʧɪ _ ajk	zɪ _ ʊs
fə _ ɚp	fə _ ɛp	pʰə _ ɔjʧ
gɪ _ if	gɪ _ æf	kʰɪ _ æwθ
bɪ _ ət	bɪ _ ejt	gə _ ʊt
pʰə _ Iʧ	pʰə _ ɑʧ	
gɪ _ l̩p	gɪ _ ɛp	
dɪ _ ɚt	dɪ _ ejt	
kʰə _ it	kʰə _ æt	
pʰə _ əf	pʰə _ ajf	
ʃə _ ɪʧ	ʃə _ ɑʧ	

Appendix B: Test words and proportion of V.CV responses in Experiment 2

cutup	0.23	titter	0.64	satin	0.74	booty	0.82
getup	0.27	fatty	0.65	attic	0.75	critic	0.82
witting	0.43	pottage	0.65	stutter	0.75	platter	0.82
footage	0.43	jitters	0.65	lattice	0.75	tittle	0.82
footing	0.45	sweater	0.65	peter	0.75	matting	0.82
quittance	0.45	mutter	0.65	otter	0.75	smiting	0.82
netting	0.45	flatten	0.65	battle	0.75	fetus	0.82
whitish	0.45	fetish	0.67	straiten	0.76	little	0.82
slattern	0.48	gutter	0.67	flutter	0.76	lighten	0.83
batting	0.48	suitor	0.67	bottle	0.76	rotor	0.83
mitten	0.48	scuttle	0.67	bitter	0.76	grotto	0.83
skittish	0.50	pittance	0.68	noted	0.77	mattock	0.83
whiting	0.50	kitten	0.68	bitters	0.77	datum	0.83
bitten	0.52	brittle	0.68	atom	0.77	chateau	0.85
splatter	0.52	stratum	0.68	brutal	0.77	rating	0.85
patter	0.52	written	0.68	pattern	0.77	fetter	0.85
hatter	0.52	petty	0.68	catty	0.77	crater	0.86
cotton	0.55	static	0.68	nutty	0.77	fated	0.86
witted	0.55	twitter	0.68	city	0.77	blatant	0.86
sweeten	0.55	clatter	0.68	smitten	0.77	titan	0.86
meeting	0.55	spittle	0.68	eaten	0.77	petal	0.86
mutton	0.55	glitter	0.68	dotage	0.77	pity	0.86
shutter	0.55	rotten	0.68	metal	0.77	platen	0.86
gotten	0.55	witty	0.68	whiten	0.77	plating	0.86
potash	0.57	critter	0.68	teeter	0.77	traitor	0.86
batten	0.57	betel	0.68	suiting	0.78	fritter	0.86
ditty	0.58	setter	0.68	gluten	0.78	treaty	0.86
letter	0.59	cutting	0.68	heighten	0.78	lighter	0.86
whittle	0.59	tatter	0.70	utter	0.78	vital	0.86
patent	0.59	putter	0.70	cootie	0.78	dative	0.87
straighten	0.61	outing	0.70	potter	0.78	vitals	0.87
lettuce	0.61	pretty	0.73	motto	0.78	splutter	0.87
outer	0.61	kettle	0.73	sputum	0.78	motet	0.87
throttle	0.62	batter	0.73	cattle	0.80	gratis	0.87
litter	0.64	bottom	0.73	glottis	0.80	flutist	0.87
mitre	0.64	mottle	0.73	atone	0.81	beauty	0.87
beaten	0.64	chatty	0.73	slaughter	0.81	prattle	0.87
status	0.64	clutter	0.74	wattle	0.82	ghetto	0.88
tattle	0.64	ditto	0.74	button	0.82	tutor	0.90

(Continued)

Appendix B: (Continued)

glutton	0.90	satire	0.92	protein	0.96	petite	1.00
chatter	0.90	detain	0.92	notice	0.96	photon	1.00
haughty	0.90	fetid	0.95	water	0.96	detest	1.00
critique	0.91	rotund	0.95	cater	0.96	pretext	1.00
crouton	0.91	latex	0.95	retire	0.96	detach	1.00
votive	0.91	tattoo	0.95	return	0.96	proton	1.00
titled	0.91	retort	0.95	loiter	0.96	daytime	1.00
writer	0.91	fatigue	0.95	scatter	0.96	quota	1.00
latent	0.91	attaint	0.95	rotate	0.96	retain	1.00
kitty	0.91	motor	0.95	atop	0.96	attire	1.00
guitar	0.91	daughter	0.95	pretend	0.96	attest	1.00
retail	0.91	neuter	0.95	grotesque	1.00	attempt	1.00
saute	0.91	duty	0.95	total	1.00	sputter	1.00
attend	0.91	liter	0.95	goatee	1.00	routine	1.00
pewter	0.91	treatise	0.95	hotel	1.00	motel	1.00
attune	0.91	photo	0.95	kowtow	1.00	atilt	1.00
putty	0.91	detour	0.96	motif	1.00		

Appendix C: Test words for Experiment 3

Tense vowel and [ɾ]	*Lax vowel and [ɾ]*	*Tense vowel and [t^h]*
duty	pity	crouton
photo	critic	latex
quota	city	protein
motive	fetish	proton
notice	static	retail
Pluto	feta	rotate
beta	gratis	butane
fetus	status	Utah
native	stratus	tutu

Tense vowel and sonorant	*Lax vowel and sonorant*	*Tense vowel and stop or affricate*	*Lax Vowel and stop or affricate*
humid	image	focus	habit
genie	planet	scuba	rapid
siren	balance	robot	decade
climate	mimic	ruby	digit
cola	very	yoga	debit
canine	spirit	tuba	rigid
tuna	minute	mucus	frigid
lilac	clinic	locust	cabin
China	relish	acorn	frigate