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Dental flaps, vowel duration and rule ordering in American English

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Abstract: This paper presents the results of an experiment which investigated dental flaps and their effect upon preceding vowel duration in American English. Twenty speakers read a randomized list of 40 disyllabic words, 20 with medial /t/ and 20 with medial /d/. Most tokens of /t/ and /d/ were pronounced as flaps, as expected. The data, collected from spectrograms, included 1st and 2nd vowel duration, presence or absence of flap (as opposed to stop [t] or [d]), duration of consonant, and extent of voicing during the flap. Our results provide evidence bearing on two phonological questions: (1) Does the rule which changes /t/ and/d/ to flaps (F) precede or follow the rule which lengthens vowels before voiced consonants (VL)? If VL precedes F, the vowels preceding flaps with underlying /d/ will have greater duration than vowels preceding flaps with underlying /t/. If F precedes VL, there will be no such difference. Our results indicate a small, but significant durational difference. (2) Do underlying /t/ and /d/, in fact, give rise to the same voiced flap consonant, as is usually assumed? The data suggest that not all /t/-flaps are identical, nor are they necessarily voiced.

Introduction

This study investigates dental flaps in American English derived from both underlying /t/ and/d/. We were concerned with ascertaining (1) the acoustic characteristics of flap consonants, and (2) whether /t/ flaps and /d/ flaps have differential effects upon preceding vowel duration. These phonetic data are offered as evidence bearing on a particular phonological question, namely, the formulation and ordering of two rules. The first is vowel lengthening, which lengthens vowels before voiced obstruents, resulting in contrasts such as [b æ: d] *vs* [b æ t]. The second is flapping, which changes an intervocalic dental obstruent to a rapidly articulated segment called a flap or tap, [bɪdɚ] or [bɪtɚ]→ [bɪɾɚ]. Sheldon (1973) examined English flaps, but with an extremely limited data corpus. His data consisted of tokens of the word pair *writer/rider* in three different sentence frames, all from a single speaker. He measured first and second syllable durations but did not obtain any information on the flap consonant itself. Comparing the ratios of first syllable duration to second syllable duration between *writer* and *rider*, he obtained somewhat conflicting results. In one sentence frame, the word *writer* was seen to have the greater ratio value, while in the remaining sentence frames, the *rider* ratios were higher.

Data collection

Our data consisted of 20 disyllabic word pairs of the *writer/rider* variety. Twenty-one speakers (10 male and 11 female) of the same American English dialect were instructed to read randomized lists which contained each of the 40 words. The lists consisted of 14 five-word groups; the first and last word in each group were not analyzed—this was done in order to minimize variations associated with differential intonation contours. Some of the list words did not contain potential medial flaps, in order to distract the speakers' attention from the purpose of the experiment. The subjects were given no instructions as to rate of speech or preciseness of articulation. As expected, most medial dentals were pronounced as flaps.

The following information was obtained from sound spectrograms for each test word: duration of first and second vowel, presence or absence of measurable consonant gap, presence or absence of aspiration, voicing during flap, and duration of consonant gap. Of course, as Lisker (1974) notes, measuring acoustic segments on spectrograms is not the same as measuring phonetic segments, which are presumably articulatory or perceptual events. Still, the acoustic data are convenient, and if the spectrograms are measured in a consistent way, it seems reasonable that those measurements ought to serve as good reflections of the *true* phonetic agents. The measuring conventions as adopted in our study were as follows: first vowel onset was fixed at the point when the first formant appropriate to the target vowel was attained; the offset of the first vowel was considered to be the cessation of first formant energy at the medial consonant gap. For the second vowel, the onset was fixed at the point of initiation of first formant energy following the consonant gap; offset was either the cessation of first formant energy at final consonant initiation, or in the case of final nasals, the point where second and third formant frequencies coalesce and nasal formants (if present) begin. Complementary to the above conventions, the flap consonant durations were measured from the cessation of first formant energy of the first vowel to initiation of first formant energy of the second vowel. The data to be presented were collected from words with medial flaps only.

Data analysis

The first question was this: Is there a significant difference in the duration of vowels preceding flaps with underlying /t/ as opposed to underlying /d/? Figure 1 shows the mean duration of the vowels preceding flaps for each /t/-flap word and its /d/-flap counterpart summed across subjects. Although the vowel durations vary considerably from one word pair to the next, all /d/-words but one have a longer first vowel. A *t*-test for related measures (Hays, 1973) shows that the mean durations of vowels preceding /d/-flaps are significantly longer than their /t/-flap counterparts ($t = 7{\cdot}13$, $P < 0{\cdot}001$). The difference corresponds to the differential vowel durations preceding voiced *vs* voiceless stops as found by Zimmerman & Sapon (1958) and Chen (1970).

The second question was this: Is there a significant difference in the first vowel/second vowel ratios in words with underlying /t/ *vs* /d/? This measure is similar to the first syllable/second syllable ratio used by Sheldon (1973), a measure perhaps preferred by those requiring that the measure of vowel duration be adjusted for variations due to speech rate, though Ohala (1970) warns that such attempts at compensation tend to increase the correlation between measures in a particular word. Figure 2 shows mean ratio values for each /t/-flap word and its /d/-flap counterpart, summed across subjects. Although there is still considerable variation from one word pair to the next, all the /d/-words but two have a larger first vowel/second vowel mean ratio. Again, using a related measures *t*-test, we find that the

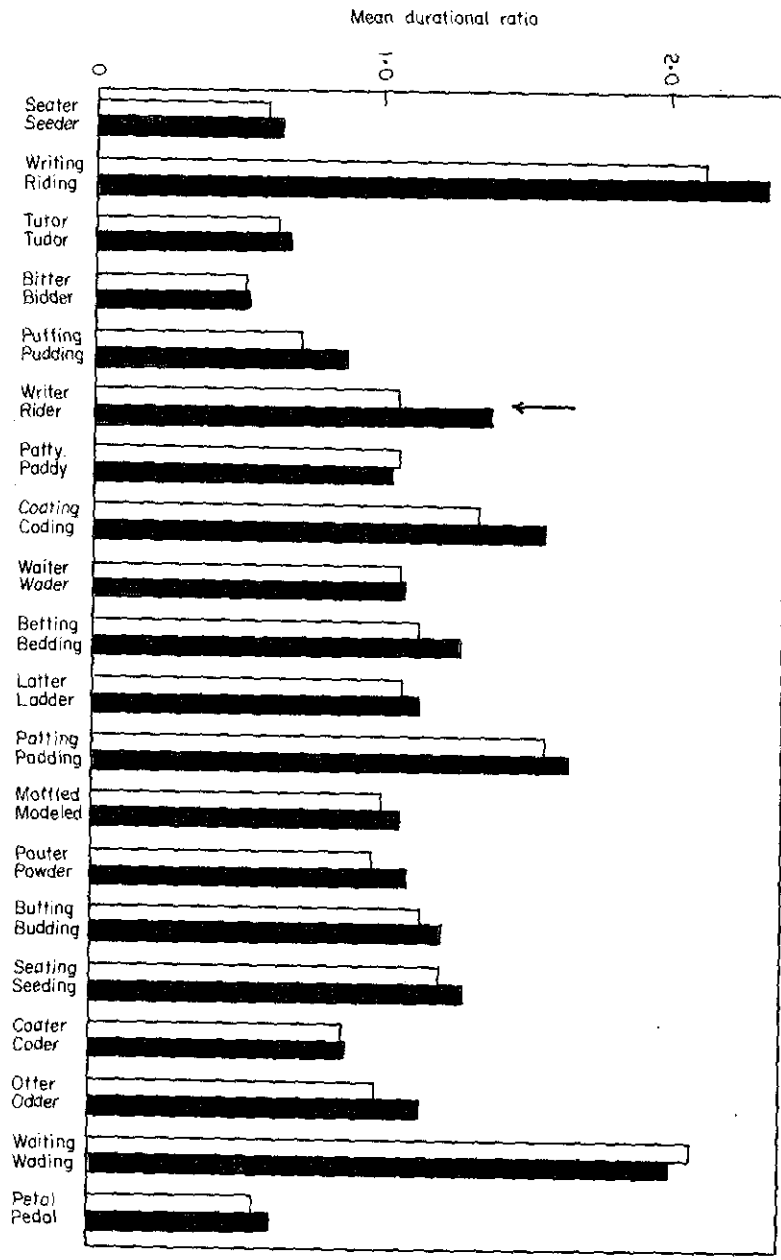

Figure 2 Mean durational ratios (first vowel/second vowel) for flapped words with underlying /t/ and /d/.

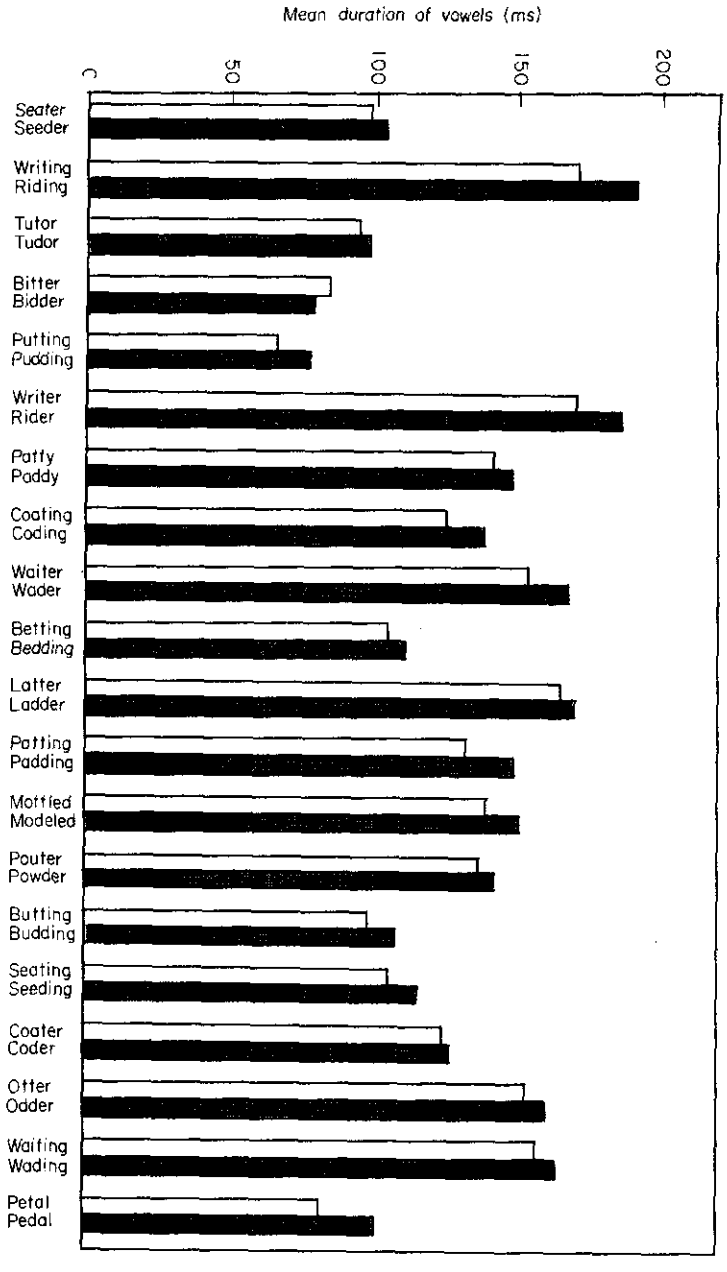

Figure 1 Mean durations of vowels preceding flaps from underlying /t/ and /d/.

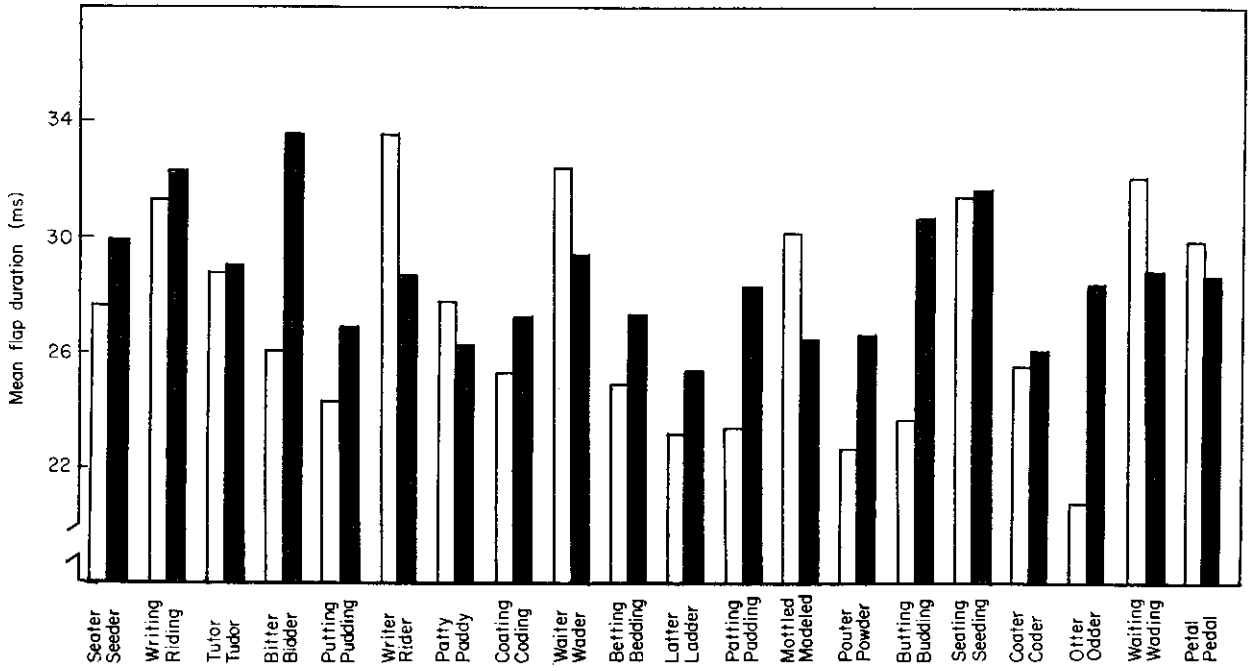

Figure 3 Mean flap durations in words with underlying /t/ and /d/.

ratio values for /d/-flap words are significantly higher than for their /t/-flap counterparts ($t = 4{\cdot}655, P < 0{\cdot}001$). The arrow in the figure points to our result for *writer/rider*, the single word pair studied by Sheldon (1973). Our data suggest that Sheldon's conflicting results stem from his extremely limited data corpus.

Finally, we were concerned with the flap itself, the main issue being the following: Is there a significant difference in the duration of the flap consonant in words with underlying /t/ *vs* /d/? Figure 3 shows the mean flap duration for each /t/-flap word and its /d/-flap counterpart, summed across subjects. A related measures *t*-test showed no statistically significant difference ($t = 0{\cdot}49$, n.s.). We thus find no difference corresponding to that found by Lisker (1957) for the duration of voiced *vs* voiceless labial and velar medial stops.

Another point concerning the quality of the flaps was whether or not flap voicing reflected an underlying voicing difference. Presence or absence of voicing for all flaps was noted, with the result that not all flaps (of either underlying type) were voiced, out of 716 flaps there were 136 voiceless flaps.

It has recently come to our attention that the difference in intensity between the first vowel and the medial consonant may have some value as a cue for /d/ *vs* /t/ (Fisher & Hirsh, 1976). Although this kind of data was not considered in our own work, it clearly deserves more study.

Discussion

From the above, we have found that mean durations of vowels preceding /d/-flaps are significantly longer than those preceding their /t/-flap counterparts. This would argue that vowel lengthening (VL) is ordered before flapping (F).

This ordering would claim that vowel lengthening is sensitive to the voicing characteristic of the underlying segment /t/ or /d/, and not to the voicing of the flap itself. Since not all flaps are voiced, another check on whether the VL—F ordering is correct would be to discover if there is a similar duration difference between vowels preceding voiced *vs* voiceless flaps, with no attention to the identity of the underlying segment. If there is no significant difference, VL—F ordering is correct. If, on the other hand, a phonetically voiced flap causes vowel lengthening, the VL could follow F. In fact, VL would have to follow a rule that arbitrarily selected the voicing value for the flap, since it was already shown that the flap voicing does not correspond to underlying voicing.

Three words in our data, *petal*, *tudor* and *mottled* exhibited a sufficient number of both voiced and voiceless flaps to allow statistical testing. *t*-Tests done on this data, the results of which are indicated in Table I, showed no significant vowel duration difference in any

Table I ***t*-Tests for the relation between first vowel duration and voicing of the following flap. Data are selected mean durations for vowels preceding voiced *vs* voiceless flaps**

Word	N	Unvoiced flap Vowel mean (ms)	N	Voiced flap Vowel mean (ms)	*t*
petal	7	81·6	7	82·7	0·178, n.s.
tudor	8	94·8	12	99·7	0·745, n.s.
mottled	9	137·6	8	141·4	0·737, n.s.

of these related to the voicing of the flap itself; thus the VL—F ordering appears to be correct, at least in the dialect of the speakers used. It seems appropriate to mention, in passing, that we know of no phonetic study which finds the reverse order to be valid, and know of one study (Fisher & Hirsh, 1976) which corroborates our results. The question can be raised whether there is in fact a dialect which maintains the order F—VL.

Our results are quite intriguing. The durational differentials between vowels before /d/-flaps as opposed to /t/-flaps are on the order of magnitude of the *universal* difference (Chen, 1970). This *universal* durational difference is argued to be due to the physiological constraints involved in producing a vowel preceding a voiced consonant *vs* voiceless consonant rather than any phonological distinction. However, this kind of explanation simply cannot hold for the present data, since the vowel duration differences are caused by abstract phonological distinctions that do not appear in the surface phonetics.

There is one further aspect of the duration difference that deserves discussion. Even though all vowels before flaps are reduced to the short vowel duration range, the slight durational differences in vowels segments with underlying voicing distinctions are maintained. This reduction is neither effected nor predicted by F. One possible solution is to add a rule following F which states that vowels are shortened before a flap, but this solution is simply inaccurate, for it does not predict the significant differences found. The real point is that vowels before flaps become shortened to some fraction of their original length, and such graduated rules do not occur in current generative phonologies.

It is not clear whether this vowel shortening applies only to the case of dental flaps. We are in the process of obtaining data similar to that presented in this paper on vowels preceding voiced and voiceless labials and velars. Our main concern is to see if (1) preceding vowels are shortened to the short vowel range and (2) if the durational differential is maintained. But even if this turns out to be the case, current phonologies cannot adequately handle the phenomena.

Another possible solution is to remove this vowel shortening effect from the realm of the phonological rules proper, to view them as a function of factors such as speaking rate, social context or situational properties. But we are not prepared to distinguish between rules based on these factors and *true* phonological rules. Furthermore, other phonological rules, such as types of vowel reduction, have a similar nature; to account for one by phonological rule and the other by reference to *performance factors* would be internally inconsistent. An adequate theory of language use must account for both phenomena—whether or not they are encompassed by phonological rule seems beside the point.

The fact remains that there are speech rules which seem dependent upon situational properties for their applicability as argued by Yngve (1975) among others. For example, one expects different phonetic output in formal speaking situations which require precise diction as opposed to informal conversational situations. In our data, it appears that some subjects interpreted the experimental task as requiring relatively precise diction rather than informal conversational speech. We are currently examining the data with reference to how such different interpretations of the speech situation might affect the acoustic properties of subjects' speech. We have also collected data from these same subjects with the purpose of investigating the effects of linguistic context and rates of speech upon various acoustic measure. Of course, we are also concerned with discovering the extent to which subjects can perceive the phonetic distinctions between /t/-flap words and their /d/-flap counterparts. These data will be reported in a later article.

Summary and conclusions

In summary, our data showed the following:

(1) There was a significant durational difference between vowels preceding flaps with underlying /d/ *vs* flaps with underlying /t/.
(2) This difference is slight; all pre-flap vowels fall within the range of short vowels.
(3) The first vowel/second vowel ratios, as suggested by Sheldon (1973) is significantly higher in words with /d/-flaps as opposed to /t/-flaps.
(4) There is no significant duration difference in the flap consonant itself linked to underlying segment identity.
(5) Though the majority of the flaps were voiced, 19% were voiceless.
(6) The actual voiced/voiceless character of the flap itself had no significant effect upon the duration of the preceding vowel.

Based on these results, the following conclusions seem warranted:

(1) The vowel lengthening rule precedes the flapping rule, at least in the dialect investigated.
(2) The physiological explanation for vowel length differences before voiced and voiceless stops is weakened.
(3) The formal structure of generative phonology is not capable of reflecting the observed duration differences.
(4) Situational or contextual variables need to be linked to the application of some phonological rules.

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