Lenition of the Flap in American English

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1 Introduction

This paper reports results from an experiment designed to test whether the flap in American English exhibits a significant difference in the degree to which it is lenited in certain domains. Results indicate the flap is weaker within words compared to across words for males but not for females, who produce flaps with consistently stronger articulations than males. The fact that males exhibit variation in the quality of their flaps poses an interesting problem for theoretical accounts that treat the flap as a categorical phenomenon, but not a gradient one. This project represents a first step in determining whether gradient aspects of the flap in American English are best understood as a planned articulation resulting from a phonological process, a natural outcome of phonetic implementation, or a combination of the two.

2 Background

The flap in American English is a lenited form of [t], [d], or [n] and it is triggered when any of these segments occurs intervocalically before an unstressed syllable, as in *water*, *ladder*, and *enter*.

The domains under which flapping occurs are limited. Flapping does not occur word-initially like in *top*, before a stressed syllable like in *baton*, or after a fricative like in *pasta* or *after* (Banner-Inouye 1995). Flapping occurs across word boundaries as in *caught 'em*, *said it*, and *paid her*, but not if the boundary marks the terminus of an intonational contour, as in *John had two apples with his coffee, and Pete, eight bananas with his milk* (Parker and Walsh 1982).

Flaps are one of the shorter articulations in English, lasting about half as long as a stop, and sometimes exhibiting only three to six pitch periods (Saw 1993, Ladefoged 1993). Despite a close relationship to taps and released alveolar stops, flaps appear to represent a unique articulation. In an articulatory comparison of flaps to taps (as in *Bertie* and *party*), Saw (1993) found that tongue-tip movements for flaps tend to be forward-backward, where for taps, tongue movements are more up-down. The reason for the difference is

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summarized by Banner-Inouye (1995), who suggests the flap gesture, unlike the tap and stop, is "ballistic" in nature, much like the hand of a pitcher releasing a ball: the tongue tip is "cocked back" then "thrown" against the alveolar ridge and quickly retracted. The uniqueness of flaps, however, is debated—this is discussed in the next section.

3 Theoretical Accounts of the Flap

Theoretical accounts of the flap generally fall into one of two categories: (1) those that treat the flap as a unique consonant articulation and (2) those that treat the flap as a byproduct of coarticulation. The first account, put forth by Selkirk (1984), Kahn (1976), and to some extent by Banner-Inouye (1995), argues that flapping is the result of a planned change in articulation by phonological environment—this is the standard, generative theory, which models the change by a switch in the set of distinctive features that categorize the consonant—thus this class of theories may be called "feature-based." For example, Selkirk argues that the 't' in *butter* is characterized by the feature [+sonorant] (a member of the class of sounds with no constriction of airflow), while the 't' in *pasta* is [-sonorant] (a member of a class of sounds that do constrict airflow). Because the featural change is constant across the different environments that cause flapping, feature-based theories predict that any environment that produces a flap will produce only one kind of flap, and no significant measurable difference between flaps should exist. The second account, offered by Browman and Goldstein (1990) and Browman and Goldstein (1992), is a "gesture-based" theory, which proposes that flaps are best understood as the result of an abstract instruction directing the tongue-tip to achieve closure at the alveolar ridge. A benefit of this analysis is that it claims to be able to explain without reference to rules and features why certain sounds, despite a perceptual difference, are in fact the same.

The gestural account departs from feature-based theories by arguing that flaps do not represent a uniquely planned articulation. Rather, flaps are essentially released alveolar stops that have been "intruded" by surrounding segments (de Jong, Beckman, and Edwards 1993; Browman and Goldstein 1992). The "open-closed-open acoustic contour" for intervocalic released stops gives rise to the percept of a flap (*butter*); whereas, for released stops after fricatives, the percept is a stop (*after*); thus, the difference between the two is perceptual (Browman and Goldstein 1992). In a study comparing the flap to alveolar stops, de Jong (1998) found that trained phoneticians listening to extractions of flaps and their surrounding vowels made a range of judgments about the categorical status of flaps: from [d], to [t] to a flap. He took this as evidence that the relationship between a flap and a full stop is

scalar, not categorical. A limitation of that study is that the flaps that de Jong used were all in the same phonological environment (across words: toa*d* on, or to*t*e on), so it is not clear if the range of variation that the flaps showed represented an unexpected patterning.

Several issues regarding the flap remain to be addressed. One question is if flaps show predicable gradient properties such that some flaps are more flap-like in some environments but more stop-like in other environments. Feature-based theories predict that flaps are stable articulations across any environment that meets its structural description. Gesture-based theories deny the uniqueness of flaps and allow for the possibility of gradient degrees of closure. If two flapping environments produce two qualities of flaps, then feature-based accounts will have been proven inadequate. However, if flaps across minimally different environments are similar, then both feature- and gesture-based theories model flapping equally well.

4 The Study

The study was designed to test whether speakers of American English exhibit variation in the quality of their flaps in normal speech. Two factors were chosen. The first factor was whether the quality of the flap would differ across a morphological boundary compared to a word boundary. For example, the italicized 't' in the underlined sections in (1-2) are both environments where a flap is expected to occur in normal speech. One question this study addressed is whether the flap in (1) is produced qualitatively different from the flap in (2).

(1) The examples were clearly sta*t*ed in the paper.
(2) The authors wondered whether to sta*t*e it in the introduction.

The second factor considered was whether the frequency with which a word occurs in normal speech corresponds to a change in the quality of the flap. For example, the verb *note* in the Kucera-Francis Word Frequency Corpus occurs 486 times, with a log frequency of 398.9. In contrast, the verb *allot* occurs only 13 times with a log frequency of 5.34. Both verbs end in [t], and when either the pronoun *it* or the past tense marker *–ed* follows the segment, it produces an environment where a flap is expected to occur. Several studies have found frequency effects associated with the perception and production of phonetic aspects of speech (Vitevich et al. 1999; Pierrehumbert 2000; Hooper 1976), so it seems reasonable that word frequency may influence the quality of the flap. So, a second question that this study addressed was

whether speakers produce flaps of differing quality in high-frequency words like *note* compared to low-frequency words such as *allot*.

4.1 Participants

Five participants, 2 male and 3 female, volunteered to take part in the study. The participants were selected because they were a friend or an acquaintance of the researcher. All of the participants were native speakers of English and originated from a variety of areas across the U.S.: Northern California, Nebraska, Seattle, Minneapolis, and rural Minnesota. The participants were not paid.

4.2 Materials and Procedure

Ten high-frequency and ten low-frequency verbs ending in [t] were chosen from the Kucera-Francis Word Frequency Corpus. The high-frequency words had a log-frequency average of 155.24, and the low-frequency words had an average of 7.15 (see appendix for complete list of verbs). Each verb was embedded in two sentences (see appendix for list of sentences). In the first, the verb was followed by past tense *–ed*, and in the second the pronoun *it*. An additional 44 filler sentences were included.

Participants were given one of five sets of sentences. For each set, the order in which the sentences were given was random, with the exception that the first and last five were filler sentences. Also, participants were randomly given one of two sentences that contained the same verb. For example, if a participant was given sentence (3), she was not given sentence (4).

(3) The candidates debated on Tuesday.
(4) The candidates decided to debate it on Tuesday.

For any set of sentences, participants were given 10 high-frequency verbs and 10 low frequency verbs which included 10 sentences with past tense *–ed* and 10 sentences with the pronoun *it*. Since measures were taken to ensure participants were not given the same verb twice, they were given 20 target sentences and 44 fillers in total.

Participants were given a packet of the sentences in 14-point Times New Roman font. Sentences were separated by triple spacing. Each packet consisted of six pages. Participants were asked to read each sentence silently first, then read it aloud "in a normal way, at a normal loudness, and at a normal rate of speaking." Participants were also told they had an opportunity to rerecord a sentence if they stumbled on their words, coughed, or were

interrupted in any way. Three of 320 recorded sentences were rerecorded, and only one was a target sentence.

A Telex M-40 microphone designed for desktop computers was used. Each sentence was recorded and saved into individual files using the sound recorder in Praat 4.0.11 running on a Hewlett-Packard 8660C Pentium III PC.

4.3 Measurement and Analysis

Lenition is defined variously. Here, the use of "lenition" will follow Banner-Inouye (1995), who draws from Pagliuca and Mowrey (1987), in suggesting that lenition is "the erosion of closure resulting from less radical muscular movement." For the flap, a lenited flap is one where the tongue tip makes less contact with the alveolar ridge than a normal flap.

In acoustic studies like this, contact must be measured indirectly. Flaps are usually measured by their length in ms, and, as mentioned already, the typical flap is about 30 ms and around three to six pitch periods. However, duration is an inappropriate measure for comparing lenition among flaps because the length of an articulation does not correlate with the degree of contact between an articulator and its goal. Two flaps with an identical length may nonetheless differ with respect to the degree to which they are each lenited. For example, compare the flap in Figure 1 to the one in Figure 2 (marked by [D]), produced by two separate speakers, M1 and F1. Both flaps are approximately 38 ms, but the energy present in the wave of the flap for M1 compared to its surrounding vowels appears less than the energy present for the wave of the flap compared to its surrounding vowels for F1.

The energy present in the waves during the flap is key to observing lenition defined here. The intuition is that energy, which is measured in decibels, is related to the amount of contact an articulator makes with its goal: Decibels directly measure, albeit on a logarithmic scale, the amplitude of sound pressure changes, which is indirectly related to the degree of openness (Johnson 1997). So, decreased energy of a flap compared to its surrounding vowels indicates greater constriction of airflow, and more contact with the alveolar ridge. The same flaps of M1 and F1 from Figures (1-2) graphed by their intensities in decibels in Figures (3-4) show such a difference. M1 produces a flap with less of a difference in intensity between its two vowels than F1 does. The deduction then is that M1 makes less contact with the alveolar ridge in his flap than F1, and so, the flap of M1 is more lenited than the flap of F1.

The measure of lenition in the experiment was obtained as follows. For each of the target flapping environments, an extraction was taken beginning

with the onset of the preceding vowel (V1) of the flapping environment and ending after the following vowel (V2). Before an analysis was made, the environment was judged by the researcher on whether the [t] was flapped or not. The extracted sections were analyzed in Praat and graphed by their intensity in dBs. For each graph, the point at which V1 exhibited its greatest intensity was averaged with the highest point of V2 to obtain a mean peak vowel intensity. The lowest point on the graph corresponding most closely with the location of the flap was subtracted from the mean vowel intensity to obtain the distance in intensity that the flap differed from its surrounding vowels. Strongly articulately flaps showed greater distance from the surrounding vowels, and heavily lenited flaps showed lesser distance. Statistical results were computed using SPSS 10.0.

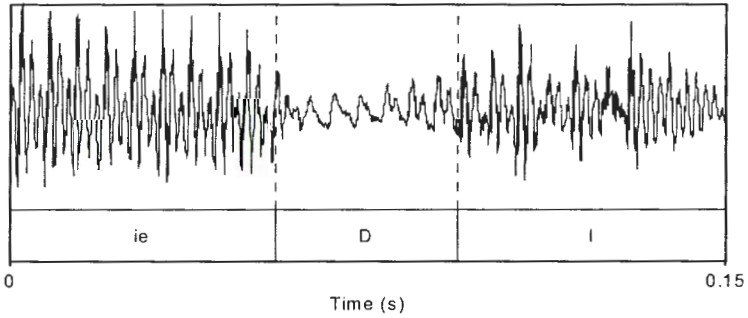


Figure 1: Waveform of F1's production of flap and surrounding vowels of *create it*

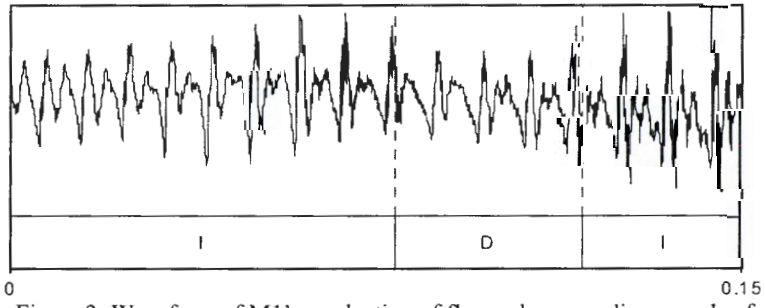


Figure 2: Waveform of M1's production of flap and surrounding vowels of *limit it*

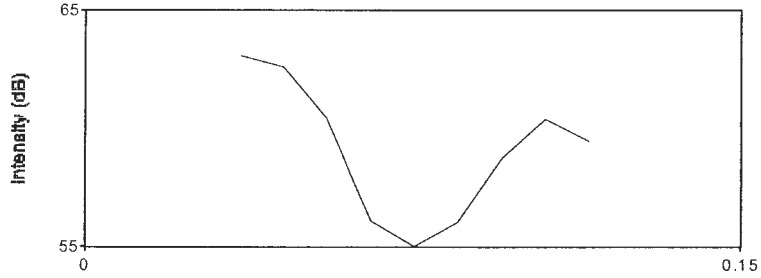


Figure 3: Intensity of F1's production of flap and surrounding vowels of *create it*

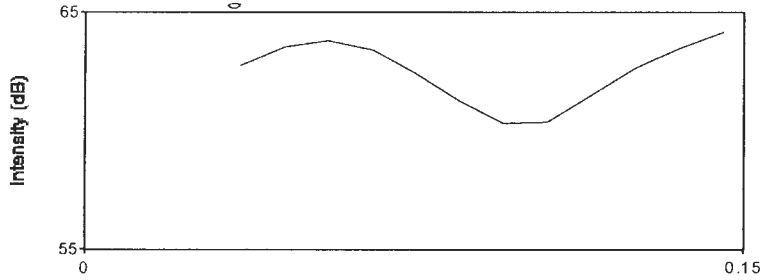


Figure 4: Intensity of M1's production of flap and surrounding vowels of *limit it*

5 Results

One hundred percent of the flapping environments exhibited a perceptible flap.

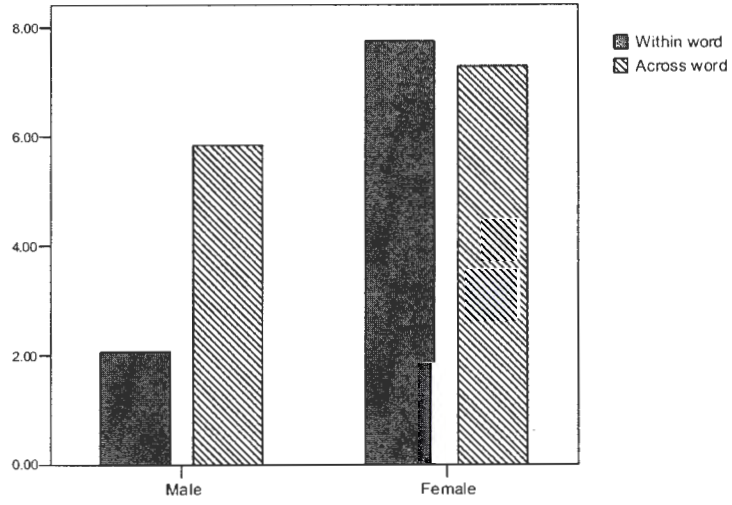
Across all participants, a repeated-measures ANOVA showed that there was no effect for either factor—for the morphological context, $F(1,4)=1.37$, $p=.31$, for the frequency context, $F(1,4)=4.78$, $p=.09$—and no interaction, $F(1,4)=1.48$, $p=.29$. However, individual ANOVAs performed separately on each subject revealed that the two male participants significantly lenited the flap within a morpheme context, "-ed," compared to across a word boundary, "it," $F(1,19)=6.78$, $p<.05$ for the first male participant (M1), and $F(1,19)=11.10$, $p<.05$ for the second male participant (M2), but exhibited no significant frequency effects, and no interaction. In contrast, the three female participants (F1, F2, F3) did not exhibit any significant lenition as a result of either factor. In fact, flaps produced by females had greater contrast with the surrounding vowels compared to the flaps produced by males,

F(1,99)=25.47, p<.001. Results for all levels and factors are shown in Table 1.

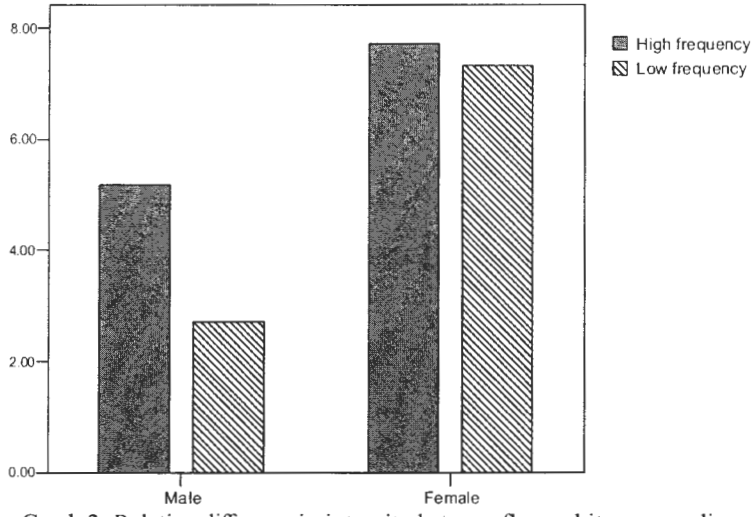
	MORPH	FREQ	MORPH* FREQ
ALL	0.31	0.91	0.30
M1	**0.02	0.06	0.85
M2	**0.00	0.09	0.10
F1	0.99	0.76	0.99
F2	0.68	0.95	0.93
F3	0.71	0.64	0.78

Table 1: Significance values from ANOVAs, by morphological and frequency factor

Graphs 1 and 2 show average difference in dB between the flap and its surrounding vowels by gender and factor level.



Graph 1: Relative difference in intensity between flap and its surrounding vowels, by morphological location of the flap and gender of speaker, in dB



Graph 2: Relative difference in intensity between flap and its surrounding vowels, by word frequency and gender of speaker, in dB

It should be mentioned that that differences between male and female values for the dependent variable is not a result of differences in physiology (i.e. that females produce flaps between vowels with more of a difference in energy than males by virtue of design). It is true that females tend to produce higher-pitched speech than males, and so, one may expect higher-pitched speech to exhibit more energy than lower-pitched speech (all other factors being equal). But, the dependent variable used here measures *relative* decibel difference between the flap and its surrounding vowels, not absolute levels of the flap in isolation. Presumably, the measure is enough to abstract away from differences between genders—and for that matter, differences between speakers.

The difference in gender reported here is consistent with Byrd (1992), cited in Byrd (1993), and Zue and Laferriera (1979). Byrd found that women produce fewer segments judged as flaps than men, and Zue and Laferriera found that men's medial [t,d]s are significantly shorter than women's.

It is also worth noting that values for M1 and M2 by frequency factor are close to significant. For these two males, flaps in high frequency words appear to be articulated slightly stronger than flaps in low frequency words. Interestingly, in a study of medial [t,d] deletion, Raymond, Dautricourt, and Hume (2003) found that frequency does not predict whether the medial al-

veolar stop deletes. Clearly, more participants are needed to confirm or deny the possibility that frequency plays a role in lenition of flapping. Naturally, this admission applies to gender differences as well.

6 Discussion

Results from participants M1 and M2 demonstrate that the quality of the flap is influenced by the morphological environment in which the flap occurs. Across word boundaries, the flap is significantly lenited compared to across morpheme boundaries. These results challenge the traditional view that flaps do not exhibit varying qualities, as feature-based theories predict. A solution for feature-based theories might be to alter the rule changing an alveolar stop to a flap so that two flaps are permitted: one stronger than the other. This seems plausible. The fact that 100 percent of the [t]s in this study were judged as flaps gives support for the conclusion that a phonological rule alters the [t] to a full flap, and then there is further process that lenites the flap within words. However, some evidence in the data reported here suggests that such an alteration would still be inadequate: There appears to be gradience between [t] and the flap as well. For example, even though all the potential flaps that participant F1 produced were judged as flaps, a full one-fourth of her "flaps" had detectible release bursts—a cue that these segments might actually be stops. This is in line with de Jong (1998)'s finding that flaps occur along a continuum from a stop to a flap. In addition to gradience between a full stop and flap, several of the flaps produced by M1 and M2 were nearly or completely deleted. Certainly, a single phonological rule capturing strong, weak, and deleted flaps as well as flaps with release bursts would hardly be able to support the conclusion that flaps represent a unique consonant articulation independent from alveolar stops.

The alternative, gestural account of flapping seems appealing because it can model scalar relationships between segments. Unfortunately, theories of flapping under this model have either been untested or produced mixed results. For example, Browman and Goldstein's (1992) position that flapping is the perception of a released stop occurring intervocalically remains to be empirically confirmed. And de Jong's (1998) study of flaps across words was unable to conclude that features or gestures alone could account for flapping. This is not a criticism of de Jong's study, as it may turn out to be the best way to understand flapping.

One obvious area for further research is a comparison of flaps and released alveolar stops within and across words. If the alveolar stops in words like *pasta* and *after* and across words like *cast her* [kæst#r] and *lost her* [lawst#r] resemble flaps with respect to (1) the distance in intensity between

the stop and its surrounding vowels, and (2) the degree of lenition within and across words, then that might suggest flaps and released stops differ only perceptually. Further, if released alveolars show variation in its quality, from flap to full stop, then the relationship among flaps and stops might, in fact, be scalar.

Appendix

Word list

Low frequency		High frequency	
Word	log freq	Word	log freq
debate	5.09	note	398.90
allot	5.34	treat	106.35
edit	5.38	complete	90.00
nominate	5.95	indicate	13.50
circulate	6.02	repeat	85.50
motivate	6.90	create	154.10
donate	6.89	permit	138.76
recruit	8.57	operate	125.10
bat	8.65	limit	121.23
spot	12.67	state	119.86

Sentence list

1. Attendance was limited to 500 guests.
2. Worried about violating fire codes, organizers decided to limit it to 500 guests.
3. The examples were clearly stated in the paper.
4. The authors wondered whether to state it in the introduction.
5. The construction worker operated the crane into the afternoon.
6. Everyone would operate it in the afternoon.
7. Mary wasn't permitted to speak.
8. The dog's owner would never permit it to bark.
9. The company created a position for Janet.
10. The artist asked to create it for an exhibit.
11. Jim looked annoyed after he repeated his intentions.
12. Jim asked his wife to repeat it to Susan.
13. Studies conducted in the past indicated a decline in interest.
14. Scientists almost never indicate it in their reports.
15. The students completed the survey in just 5 minutes.
16. Students were asked to complete it in 5 minutes.
17. The victim was treated for severe burns.

18. The victim wondered if the nurse would treat it with salve.
19. Several investigators noted the blood stain.
20. The investigators said they'd note it in their summary.
21. The candidates debated on Tuesday.
22. The candidates decided to debate it on Tuesday.
23. The testing service allotted 10 extra minutes for the verbal section this year.
24. The teachers of third period refused to allot it for test-taking purposes.
25. The reporter usually edited his articles well ahead of deadline.
26. The reporter would usually edit it on Tuesday.
27. Six teachers at the high school nominated the paper for an award.
28. Six teachers at the high school wanted to nominate it for an award.
29. The company donated several thousand dollars to the charity.
30. The company was happy to donate it to the charity.
31. The letter was circulated around the office.
32. Office workers encouraged Mark to circulate it around the office.
33. John's dog was recruited for a dog-sledding race.
34. The dog-sledders hoped to recruit it for an upcoming race.
35. The baseball player batted at the ball.
36. The baseball player tried to bat it to left field.
37. Jane thought she spotted the car in the lot.
38. Jane looked for her car but couldn't spot it at all.
39. The cat wasn't particularly motivated to move for the guests.
40. The cat owners weren't successful to motivate it to move for the guests.

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