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Incomplete Neutralization in American English Flapping: A Production Study

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Abstract

This paper presents a production study of incomplete neutralization in American English flapping. In flapping, /d/ and /t/ both become a voiced flap in certain prosodic contexts (see, e.g., Kahn 1980). A number of studies show that this neutralization is incomplete: /d/-flaps can be distinguished from /t/-flaps on the surface (Fox and Terbeek 1977). Other studies, however, have found conflicting results (Port 1976). This study finds that flapping is an incompletely neutralizing process,Äî/d/-flaps and /t/-flaps can be distinguished on the surface by the duration of the preceding vowel, at least for some speakers. Additionally, some studies find evidence that hyperarticulation and orthography have an effect on whether neutralization is complete or incomplete (Fourakis and Iverson 1984, Warner et al. 2006). The present study employed two tasks: a minimal pair reading task, designed to increase these potential effects, and a morphological paradigm completion/"wug" task, designed to reduce these effects. No significant differences between the two tasks were found, thus failing to support the claim that incomplete neutralization is due to these extragrammatical factors.

Incomplete Neutralization in American English Flapping: A Production Study

Aaron Braver*

1 Introduction

While a number of studies report evidence of incomplete neutralization in a variety of languages and contexts (Fisher and Hirsh 1976, Fox and Terbeek 1977, Zue and Laferriere 1979, Port and O'Dell 1985, Dinnsen and Charles-Luce 1984, Slowiaczek and Dinnsen 1985, Slowiaczek and Szymanska 1989, Dmitrieva 2005, van Oostendorp 2008, among others), other studies have either not found such evidence, or argue that such effects are due to extragrammatical factors such as the influence of orthography or hyperarticulation in the laboratory setting (Fourakis and Iverson 1984, Warner et al. 2006, Joos 1942, Port 1976).

In this paper, I present a production study of one putative case of incomplete neutralization: flapping in American English. The study is designed to address the following questions: (a) is there incomplete neutralization in American English flapping? (b) Is it affected by the particular task in which a speaker is engaged? The experiment described here (a) shows an overall effect of incomplete neutralization, and (b) shows an effect of task type on a reflex of the voicing contrast, but not on whether neutralization is complete or incomplete. The current study is further motivated by a recent rise in the use of incomplete neutralization in arguing for particular models of the phonetics-phonology interface (see Section 1.2).

1.1 Incomplete Neutralization

I adopt the formulation in (1) as a definition of incomplete neutralization:

(1) An input-output mapping is *incompletely neutralizing* if two (or more) distinct elements in the same context differ in the phonological input, and a trace of this distinction is maintained in the phonetic output.[1]

Incomplete neutralization, then, can be compared to complete neutralization, in which no trace of an underlying distinction persists on the surface, or a situation with no neutralization, in which a full distinction persists on the surface.

The study on German "final devoicing" reported by Port and O'Dell (1985) is illustrative. Minimal pairs were constructed, differing only in the underlying voicing status of their final consonant (for example: *Rat* 'advice' and *Rad* 'wheel'). While a broad transcription might render both of these words as [ʁat], Port and O'Dell report a consistent distinction between the set of underlying voiceless-final (*Rat*) and voiced-final (*Rad*) words. In this study, the vowel preceding the final consonant in each of the underlyingly voiced-final words was longer (by approximately 15ms) than those in the underlyingly voiceless-final words. Since vowels preceding voiced consonants generally tend to be longer than those preceding voiceless consonants in non-neutralizing contexts (Chen 1970), these data would seem to suggest that some trace of the underlying voicing status of the final consonants is maintained on the surface in the so-called "devoicing" context.

1.2 Previous Studies and Theoretical Claims

Experimental studies of incomplete neutralization have tended to focus on cases of final devoicing, as with the German example in the previous section. A sample of additional languages in

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[1] The dividing line between a "trace" of an underlying distinction and a full-fledged maintenance of the contrast, which maps to the difference between incomplete neutralization and non-neutralization, is not discussed here for reasons of space.

which incomplete neutralization in devoicing contexts has been reported includes Catalan (Dinnsen and Charles-Luce 1984), Polish (Slowiaczek and Dinnsen 1985, Slowiaczek and Szymanska 1989), Russian (Dmitrieva 2005), and Dutch (Warner et al. 2004, Ernestus and Baayen 2007).[2]

Final devoicing had long been championed as a case of *complete* neutralization (see Jakobson et al. 1952/1975 as an early example), perhaps accounting for its prominence in studies of incomplete neutralization. Additionally, voiced and voiceless segments tend to vary along a variety of measures: length of preceding vowels, intensity dip during closure, and effects on F0 and F1 (Lisker 1986, Kingston and Diehl 1994), among others. If just one of these measures fails to completely neutralize in a devoicing context, one could plausibly claim that the neutralization was incomplete.

Others, however, have argued that putative cases of incomplete neutralization are due to extra-grammatical factors. Fourakis and Iverson (1984), for example, argue that the alleged case of incomplete neutralization in German devoicing results from "hypercorrect spelling pronunciation" in the laboratory setting, and that the neutralization is complete in more natural contexts: tokens elicited during a word-list reading task showed divergence between underlyingly voiced and voiceless forms, while tokens elicited as part of a morphological paradigm task did not. Similarly, Warner et al. (2006) present a putative case of incomplete neutralization in Dutch, in which controlling for orthographic distinctions leads to complete, rather than incomplete neutralization.

Contexts other than final devoicing have also been proposed as cases of incomplete neutralization; flapping in American English is one such case. In flapping, underlying /d/ and /t/ become output [ɾ] intervocalically in certain prosodic configurations (see, e.g., Kahn 1980). A number of studies have suggested that flaps stemming from underlying /t/ ("/t/-flaps") are distinct from those stemming from underlying /d/ ("/d/-flaps"). Reported surface distinctions include length of the preceding vowel, degree of intensity dip during closure, and closure duration (Fisher and Hirsh 1976, Fox and Terbeek 1977, Zue and Laferriere 1979, Huff 1980).[3] Since these measures are reflexes of voicing, these studies amount to evidence that derived flaps in American English maintain some trace of their underlying voicing status on the surface. Other studies, however, report that flapping is completely neutralizing, at least for some speakers (Joos 1942, Port 1976).[4]

A number of recent theoretical proposals attempt to either capture or capitalize on the existence of incomplete neutralization, providing additional motivation for the current study. For example, van Oostendorp (2008) has used incomplete neutralization in final devoicing as evidence for "turbidity" as a theory of faithfulness in Optimality Theory. This modified Containment model (Prince and Smolensky 1993) allows a three-way distinction in the representation of voicing, which he maps to underlyingly voiceless segments, segments that are voiced both in the input and the output, and segments that have been devoiced. Since devoiced segments have a different representation than underlyingly voiceless segments, the phonetics could potentially make sub-phonemic alterations to devoiced segments (resulting in the appearance of incomplete neutralization) while leaving underlyingly voiceless segments unaffected.

Similarly, Gouskova and Hall (2009) argue that incomplete neutralization can be modeled as access by the phonetics to intermediate stages in a phonological derivation. They present a study showing that epenthetic vowels in Lebanese Arabic are either shorter, backer, or both shorter and backer than their lexical counterparts. Following the assumptions of Optimality Theory with Candidate Chains (McCarthy 2007), they take a candidate to consist of a derivational chain from the phonological input to the phonological surface form, with gradual, incremental steps along the way. Under their proposal, epenthetic [i] begins null, and at each step in the chain becomes a less sonorous vowel, as in (2).

(2) Candidate chain for epenthesis of [i]:
/CC/ <CC, CɨC, CəC, CiC>

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[2] See Warner et al. (2006) and Ernestus and Baayen (2006) for additional studies that complicate the claims made for Dutch.

[3] Huff's (1980) study examines New York City speakers, and finds complete neutralization in some vocalic contexts, and incomplete neutralization in others.

[4] The study in Port (1976), part of his dissertation, examined intervocalic lenition in a number of consonants (not just alveolars) and was restricted to vocalic contexts including [ɪ].

If phonetics can access this entire chain, they argue, epenthetic vowels in Lebanese Arabic could be realized as one of the non-final steps in the chain, explaining why epenthetic [i] is sometimes realized closer to [ɨ] or [ə].

1.3 Goals of this Study

This study has two main goals. The first goal is largely empirical: to investigate the presence or absence of incomplete neutralization in American English flapping. This goal is motivated by the disagreement in the literature with regard to both flapping specifically and incomplete neutralization more generally. Second, this study asks a methodological question: does the type of task used in experiments of incomplete neutralization affect whether neutralization is complete or incomplete? Specifically, the experiment consists of two tasks: one designed to increase the possible influence of extragrammatical factors, and one designed to reduce those effects.

2 Methods

The experiment was divided into two tasks (with order randomized by speaker), each separated by a short set of arithmetic problems (lasting approximately 5 minutes). The first task was a minimal pair reading task designed to induce hyperarticulation. The second task was a paradigm completion ("wug") task, designed to reduce hyperarticulation and effects of orthography. Tokens from both tasks were examined for incomplete neutralization of flaps, and the results were compared to identify any differences among the two tasks.

2.1 Speakers and Recording

14 native English speakers, all undergraduates raised in New Jersey, participated in this experiment. Speaker 9 failed to accurately reproduce a majority of the stimuli as presented, so this speaker's data was not included in the analysis. Of the 13 remaining speakers, 10 were female, 3 were male. All recordings were performed in a sound-attenuated recording booth, using an AT44040 Cardioid Capacitor microphone with a pop filter, amplified through an ART TubeMP microphone pre-amplifier (JVC RX 554V). The speech was digitized as WAV files at a sampling rate of 44.1kHz using Audacity. Acoustic analysis was performed using Praat.

In both tasks, each token was recorded twice. Only the second repetition of each token was analyzed since in many cases the participants stumbled slightly in their pronunciation of the first repetition. When the second token was deviant, or boundaries could not be determined, the first token was used instead. If both repetitions were deviant, the item was excluded.

2.2 The Minimal Pair Reading Task

2.2.1 Stimuli

30 bisyllabic nonce verbs were created, half with final /d/ and half with final /t/, forming 15 minimal pairs. The first syllable of each nonce word was either *re-* or *un-*, actual verbal prefixes in English, in order to encourage the participants to accept these words as possible English verbs. The onset of the second syllable was varied so as not to clash with existing English words (all onset segments were voiceless). The vowels in the second syllable were divided evenly among high, mid, and low vowels. The English progressive *-ing* suffix was then added to each form, putting the formerly word-final /d/ or /t/ of the nonce verb into a flapping environment. See Table 1 in the Appendix for a full listing of stimuli used in this task.

2.2.2 Procedure

Speakers were presented visually with the progressive form of each member of the target minimal pair simultaneously, in frame sentences, as in (3):

(3) John was unketting this whole week.
John was unkedding this whole week.

This procedure was repeated for all 15 minimal pairs, randomized, with 30 distractors. Within each minimal pair, the order of the /d/-form and the /t/-form was randomized.

The minimal pair reading task was designed to heighten both hyperarticulation and orthographic influence. Since the stimuli were presented in the form of minimal pairs, speakers clearly saw an orthographic distinction between the two forms they were asked to read. Unlike the wug task (see the following section), speakers were not engaged in any tasks other than reading aloud, allowing for them to focus more intently on their pronunciation, thus making hyperarticulation more likely.

2.3 The Paradigm Completion ("Wug") Task

The paradigm completion task followed a modified version of Berko's (1958) "wug" task in order to direct the participants' focus towards filling in a morphological paradigm rather than on pronunciation (for a use of a morphological paradigm task in the study of incomplete neutralization, see Fourakis and Iverson 1984).

2.3.1 Stimuli

30 bisyllabic nonce verbs, distinct from those in the minimal pair reading task, were created. Half had word-final /d/ and half had word-final /t/, but were not organized as minimal pairs. The tokens were of similar form to those in the minimal pair task, with the first syllable consisting of either *re-* or *un-*, and second syllables consisting of voiceless onsets, an equal number of high, mid, and low vowels, and a /d/ or /t/ coda. See Table 2 in the Appendix for a full list of stimuli used in this task.

2.3.2 Procedure

Each nonce verb was put into a frame sentence (without the progressive suffix) that unambiguously identified it as a verb, as in (4):

(4) John learned how to unteed this week.

Speakers were shown this sentence on a screen, followed by a screen with a frame sentence and a blank, designed to elicit the progressive *-ing* form of the nonce verb, as in (5).

(5) In fact, he was ________ this whole week.

After an initial training period, speakers were able to reliably fill in the desired form when reading aloud (i.e., they would read (5) as "In fact, he was unteeding this whole week"). As with the minimal pair reading task, when these tokens are put in the progressive form, the formerly word-final /d/ or /t/ is placed into a flapping environment.

This procedure was designed to reduce effects of both hyperarticulation and of orthography (Fourakis and Iverson 1984). Since speakers are engaged in a morphological task, their attention was directed away from pronunciation. Similarly, since speakers are not being shown two forms at the same time (as they were in the minimal pair task), they do not have an obvious orthographic distinction to maintain. Finally, since the screen displayed a frame sentence with a blank during the production of the actual (progressive form) target token, speakers were not reading the token, but rather generating it based on the application of a morphological process to a newly-learned nonce word. There is, of course, the potential that the orthographic form of the uninflected verb, which speakers were shown, could have affected their production of the progressive form.

2.4 Measurements

Since phonological contrasts like [voice] have a variety of acoustic correlates (Lisker 1986, Kingston and Diehl 1994, Stevens and Blumstein 1981), one can reasonably ask how many of these reflexes must be divergent between two forms in order to consider neutralization to be incomplete. In terms of voicing, voiced segments have longer preceding vowels (Chen 1970), shorter closure duration (Kluender et al. 1988), and lower F0 and F1 on surrounding vowels (Kingston and Diehl 1994, Hombert et al. 1979) than voiceless segments (see Braver 2010 for a discussion of the relevant acoustic cues).

While each of these reflexes of voicing was measured for each token in this experiment, only preceding vowel duration will be discussed due to space limitations. The duration of these vowels was measured from the onset of voicing to the onset of the flap closure. The onset of flap closure was marked as the location on the spectrogram with a marked reduction in formant structure, accompanied by a drop in intensity and periodic energy as seen in the waveform.

In order to remove tokens that may not have had a flap articulation, the distribution of /d/ tokens and /t/ tokens for the measures listed above, as well as for percent of closure voicing (as determined by Praat's voicing report function), was examined. The distribution was not obviously bimodal for these measures, which would have indicated a clear categorical distinction between flaps and unreduced alveolar stops. As a cutoff point, tokens more than 2 standard deviations from the mean on these measures were considered outliers and discarded.

2.5 Statistical Analyses

A linear mixed model (Baayen 2008) was run using the `lme4` package in R. The duration of pre-flap vowels was regressed against a model in which underlying voicing status (/t/ or /d/), task, and vowel height were fixed factors, and speaker and item were random factors. Vowel height, which was contrast coded, was included to soak up variability since it is known to affect vowel duration (Peterson and Lehiste 1960, Lehiste 1970). An interaction term between underlying voicing status and task was also included to investigate an effect of task on degree of neutralization (that is, the interaction term reflects effects of underlying voicing status that may be present in one task, but not the other).[5]

3 Results

In this section, I lay out the results of the two tasks pooled across all speakers. Individual speaker differences are not discussed, due to space limitations.

3.1 Underlying Voicing Status

To support the hypothesis that flapping in American English incompletely neutralizes /t/ and /d/, a significant distinction would need to be found between /t/-flaps and /d/-flaps on some correlate of voicing. As indicated in Section 2.4, this paper focuses on the duration of pre-flap vowels. The mean duration of vowels preceding /t/-flaps and /d/-flaps is shown in Figure 1. The overall mean duration of vowels preceding /d/-flaps was 8.76ms longer than the mean duration of vowels preceding /t/-flaps ($t = -2.105, p < 0.05$).

3.2 Task

Two types of task effect are considered here. The first is the main effect of task on pre-flap vowel duration, which investigates the relationship between the task at hand and duration of pre-flap vowels.

[5] The procedure for calculating degrees of freedom in this type of model has not yet been discovered, so the significance of the coefficients was checked by the Markov Chain Monte Carlo method, using the `pvals.fnc` function of the `languageR` package for R.

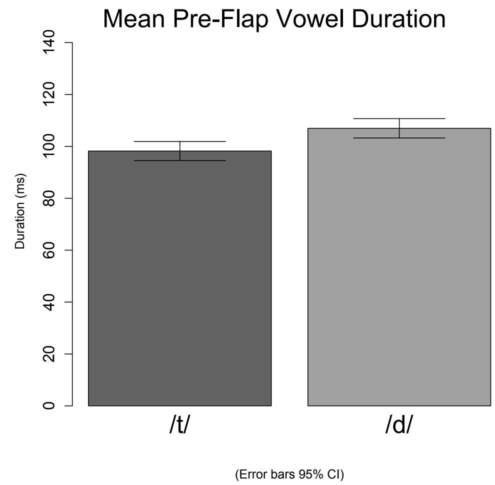

Figure 1: Mean duration of pre-flap vowels by underlying voicing status.

The second is the effect of the interaction of task and underlying voicing status on pre-flap vowel duration, which highlights effects of underlying voicing status that may be present in one task but not in the other: in other words, whether the change in vowel duration between /d/-flaps and /t/-flaps varies based on whether that token was from the wug task or from the minimal pair task.

3.2.1 Main Effect of Task

There was a significant main effect of task on pre-flap vowel duration. As can be seen in Figure 2, pre-flap vowels were overall longer in the wug task than in the minimal pair task regardless of their underlying voicing status (mean difference: 12.21 ms, $t = 4.378, p < 0.001$).

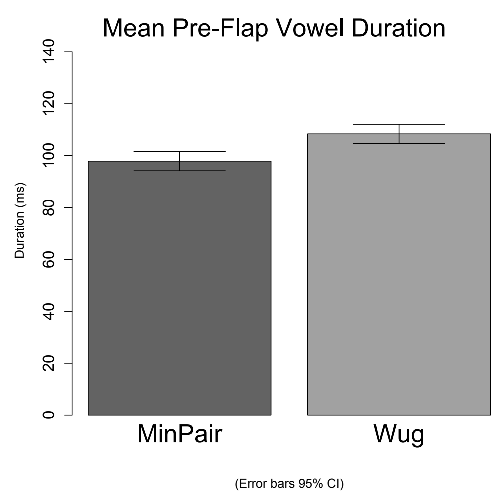

Figure 2: Mean pre-flap vowel duration by task.

3.2.2 Interaction of Task and Underlying Voicing Status

The effect of the interaction of task and underlying voicing status on pre-flap vowel duration was not significant ($t = -0.245, n.s.$). Figure 3 shows the mean vowel duration for /t/-flaps (on the left) and /d/-flaps (on the right), separated by task (triangles represent the means from the wug task, circles the means from the minimal pair reading task). The near parallel slopes of the two lines represents the similarity of the difference between /d/-flaps and /t/-flaps in the two tasks. The fact that the wug /t/-flaps and /d/-flaps are both higher than the minimal pair /t/-flaps and /d/-flaps is a reflection of the main effect of task described in the previous section.

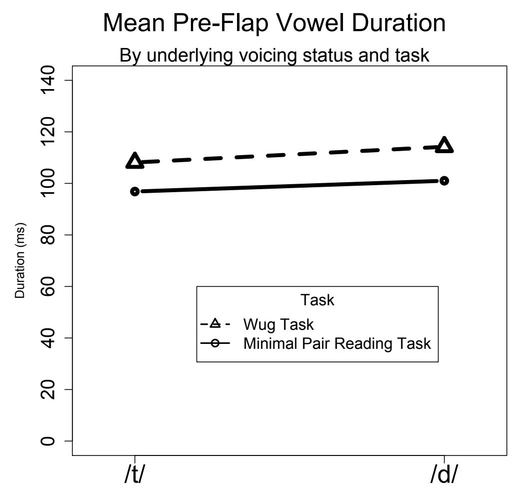

Figure 3: Mean pre-flap vowel duration by task and underlying voicing status.

4 Discussion

4.1 Incomplete Neutralization in American English Flapping

In order for an input-output mapping to be incompletely neutralizing according to the definition in (1), some trace of an underlying distinction must be realized in the phonetic output. In the case of American English flapping examined here, the underlying distinction at issue is a voicing contrast. As summarized in Section 1.2, there has been disagreement in the literature as to whether flapping is a case of incomplete neutralization. This study found an effect of underlying voicing status on pre-flap vowel duration, suggesting that whether a given flap token originated as a /t/ or a /d/ had an impact on the duration of the preceding vowel. As such, a trace of the underlying distinction between /t/ and /d/ is maintained on the surface, even in flapping contexts.

This finding is in line with those outlined in Section 1.2 that found incomplete neutralization in American English flapping. Unlike these previous studies, however, the tokens in this experiment were all nonce words instead of actual English words.[6] Experiments with actual words have the disadvantage of being prone to effects of lexical frequency. If the words with /t/ were more frequent than the words with /d/, for example, we might expect that the /t/-words were reduced more than the /d/-words and thus had a shorter vowel duration. There is, however, a potential pitfall to the use of nonce words in this type of study. Since words with higher lexical frequencies are more likely to reduce (Bybee 2000, 2001), we might expect nonce words to resist reduction. In such a situation, a

[6]Port (1976), which did not find any effects of underlying voicing status on preceding vowel duration, used "possible English words" rather than actual English words.

/t/∼/d/ distinction on the surface would be an example of a non-neutralized contrast rather than of incomplete neutralization. I take the significant findings of incomplete neutralization in *both* types of studies, however, as evidence for the existence of incomplete neutralization in the flapping of at least some speakers of American English.

4.2 Effects of Extragrammatical Factors

While there was a significant main effect of task (pre-flap vowels were longer in the wug task, regardless of their underlying voicing status), there was not a significant effect of the interaction of underlying voicing status and task on the duration of pre-flap vowels. This finding does not lend support to the hypothesis that a hyperarticulation-inducing task that involves reading overt orthographic forms will lead to a greater likelihood of incomplete neutralization than a hyperarticulation-reducing task that obscures the link between orthography and the target form. As such, it cannot be concluded that these factors are responsible for the difference between the studies which have found incomplete neutralization in flapping contexts and those that have not.

4.3 Additional Considerations

While the current experiment shows evidence of incomplete neutralization in the flapping context and fails to provide evidence of the influence of extragrammatical factors on this phenomenon, there are some remaining concerns. A second study, designed to address these concerns, is currently underway. In the study described in this paper, onsets of target syllables were either simple (a single voiceless segment) or complex (/s/, followed by a single voiceless consonant). The linear mixed model from the main experiment was rerun with onset type and the onset type/underlying voicing status interaction as fixed factors. While vowels following complex onsets were longer ($t = 7.493, p < .001$), the interaction term was not significant ($t = 0.148, n.s.$). In the upcoming study, only simple, voiceless onsets are used.

Similarly, while none of the stimuli in this experiment were actual English words, some substrings within the stimuli did clash with actual English words. Since the stimuli were presented as English verbs, and the first syllable of each token was an English verbal prefix (*un-* or *re-*), participants may have decomposed the tokens into prefixes and roots. Tokens in which this root clashed with an actual English word showed longer pre-flap vowels than those without (mean difference: 1.97ms, $t = -2.429, p < 0.025$); however, there was not a significant interaction of underlying voicing status and root clash ($t = 0.478, n.s.$). In order to prevent any undue influence from this factor, the upcoming experiment presents the stimuli as monomorphemic, and does not use any English verbal prefixes.

As an additional consideration, the upcoming experiment uses the same set of tokens in both tasks, unlike the current experiment (participants wait at least a week between tasks, to reduce any potential effects of having heard the tokens before). This design has the added benefit of eliminating the distinction between those tokens that have a minimally differing token somewhere within a given task (e.g., all of the tokens in the minimal pair task) and those that do not (e.g., many of the tokens in the wug task).

In order to provide further evidence that the incomplete neutralization seen here is, in fact, part of speakers' grammar, a perception study should be run to see if and how speakers distinguish between /t/-flaps and /d/-flaps. If speakers are able to distinguish /d/-flaps from /t/-flaps in natural speech, it would serve as further evidence of the existence of incomplete neutralization.

5 Conclusion

This study has followed in a line of work examining the empirical basis of incomplete neutralization. In line with a number of studies in the past, this study found an overall pattern of incomplete neutralization in American English flapping with respect to the duration of pre-flap vowels. It was also shown that a task designed to increase effects of hyperarticulation and orthography did not make incomplete neutralization more likely than a task designed to reduce these effects, thus eliminating one potential source of the discrepancy between studies that found incomplete neutralization in flapping and those that did not.

This study, especially when taken together with previous studies finding incomplete neutralization in flapping, indicates that incomplete neutralization is, indeed, present in this context, at least for some speakers. While effects of incomplete neutralization in other languages and contexts have been argued to be due to effects of hyperarticulation and orthography, the results presented here do not suggest that this is the case for flapping.

Appendix

rekadding	rekatting
resteeding	resteeting
unkadding	unkatting
reskeeding	reskeeting
respedding	respetting
unpadding	unpatting
rekeeding	rekeeting
unskadding	unskatting
unskeeding	unskeeting
unskedding	unsketting
unspedding	unspetting
restadding	restatting
unstedding	unstetting
restedding	restetting
unsteeding	unsteeting

Table 1: Stimuli from minimal pair reading task.

unteed	retedd
unkeed	rekedd
unpede	repedd
resheed	reskedd
unspeed	untedd
reteet	retet
unkeet	unket
retad	resket
respeet	reket
unteet	untet
unspat	rekad
respad	unspad
unstad	retat
unpete	untat
unstat	repat

Table 2: Stimuli from wug task.

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