THE ARTICULATORY REALITY OF CORONAL STOP 'DELETION'

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ABSTRACT

Coronal Stop Deletion has been the subject of sociolinguistic inquiry in several varieties of English, and has enjoyed a special place in the pantheon of variable linguistic phenomena since its first description in [6]. Robust morphological conditioning (more deletion in monomorphemes like *pact*, than with -ed suffixes like in *packed*) suggests a phonological rather than phonetic character. However, the presumption of a categorical, structure-preserving, deletion process is largely an artifact of the articulatory-acoustic relation in stop consonants; anything less than full closure is not perceived as a stop. I present Electromagnetic Articulography results from the speech of several native speakers of American English, finding that deletion without residual tongue tip raising is rare, but some individuals produce articulatory categories that correlate non-deterministically with perceived deletion. Further, the investigation of a gradient measure for degree of tongue tip raising reveals systematic effects of articulatory interval duration, task, and morphological class.

Keywords: EMA, articulation, variation, phonetics-phonology interface

1. INTRODUCTION

Linguists interested in variation and the phonetics-phonology interface have been grappling with the deletion of word-final coronal stops in English for half a century. Coronal Stop Deletion (CSD, sometimes called '/t,d/ Deletion') can be characterised as the surface absence of an underlying coronal stop that follows a consonant at the end of a word:

(1) $C^{COR} \rightarrow \emptyset$ / C _ #

The process has garnered particular attention because, in addition to varying rates of application according to phonetic environment, researchers have observed that word-final coronal stops delete at different rates according to their word's morphological class. The basic pattern is for monomorphemic stops (e.g. in *pact*) to undergo deletion more frequently than words where the coronal stop constitutes an -ed suffix (e.g. *packed*). Semiweak verbs, which form the past with both a vowel change and a coronal stop (e.g. *kept*), are typically found to participate at an intermediate rate. This morphological conditioning has been robustly attested in almost every variety of English investigated, though the size of this effect may be smaller in British Englishes [10, 11]. Evidence for a morphological effect is key, because this situates CSD squarely in the phonology under a strict modular view that prohibits a morphology-phonetics interface.

1.1. Interrogating presumed categoricity

More recent investigations into CSD, as well as work outwith sociolinguistics, have questioned some of the assumptions inherent to mainstream approaches. In particular, Browman and Goldstein [2] provide X-Ray Microbeam evidence for inaudible tongue tip raising for a coronal stop in the sequence *perfect memory*. They demonstrate that an articulation of comparable magnitude to an audible coronal stop can be rendered inaudible due to temporal overlap of surrounding closures (in this case a preceding dorsal and following labial closure). This evidence is used to motivate the Articulatory Phonology [3] framework, which seeks to recast such apparent allophony as products of the physiological demands of articulating several gestures in a short space of time.

The perspective that apparent instances of CSD are the result of gradient phonetic parameters gains credence from the idea that morphological conditioning on rates of CSD could be emergent from other correlated factors like lexical frequency [4]. Thus, CSD need not be a discrete phonological phenomenon. Further, Temple [13] demonstrates a number of confounding factors in the typical interpretation of acoustic data for the purposes of investigating CSD, which have been overlooked in the vast majority of literature on the topic.

1.2. Categoricity, gradience, and the grammar

Other contemporary analyses continue to take the CSD's morphological conditioning seriously, but concede that some portion of apparent CSD must be attributed to the gradient phonetics. These

theoretical models make different predictions about where we should find categorical CSD outcomes. Myers [7] and Bermúdez-Otero [1] draw upon Guy's [5] account of CSD across a stratified morphophonology. They stipulate that a gradient implementation of CSD – 'Coronal Stop Lenition' – must be constrained to the phonetic module. So monomorphemes, which pass through several levels of categorical phonology, should exhibit a higher rate of categorical deletion than complex words with an -ed suffix. However, Tamminga [12] reports that CSD in words with an -ed suffix exhibits priming behaviour consistent with a zero-allomorphy explanation. Whatever portion of CSD in -ed suffixed words can be attributed to zero-allomorphy, this should manifest as a categorical outcome in terms of articulation.

Interestingly, the predictions from Myers [7] and Bermúdez-Otero [1] and Tamminga [12] are not necessarily mutually exclusive. Something resembling a categorical implementation of CSD could take place in both the morphology and phonology. However, Bermúdez-Otero [1] stipulates that the phonology need not be structure-preserving, and a token with residual tongue-tip raising may still be a member of a category that is distinct from full [t]. In other words, full [t] and undershot [t] could be allophonic outputs of a phonological CSD process. Zero-allomorphy, on the other hand, must present itself as a true articulatory zero; if there was never a coronal stop to begin with, there is no reason to expect tongue tip raising.

2. DATA & METHODS

2.1. Procedure

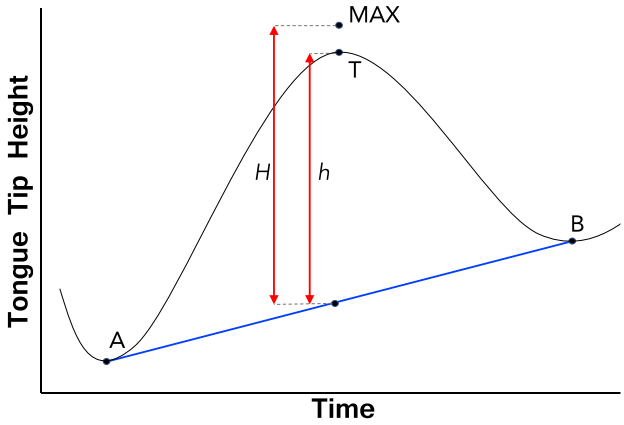
Synchronised acoustic and articulatory data for 5 native speakers of American English were recorded using an NDI Wave Electromagnetic Articulograph (12 subjects recruited, data from 2 found corrupted and discarded, 5 turned away for ineligibility). Subjects performed several tasks designed to elicit quasi-naturalistic speech: a map task, a semantic differential task, two reading passages, and two word lists. This was based on the design of the ESPF DoubleTalk Corpus [9], but modified to prompt as many relevant items from each speaker as possible. Suitable tokens were instances of underlying word-final coronal stops following a consonant, with no adjacent coronal segments. The procedure yielded acoustic and articulatory data for 362 tokens in total.

Electromagnetic Articulography (EMA) sensor coils were adhered to three active articulators: the tongue tip (TT), tongue dorsum (TD), and lower lip (LL). In addition, speakers wore a lensless glasses frame held in place with surgical tape, with three more sensors aligned at the bridge of the nose and each mastoid to define the sella-nasion plane. This plane was used to define new axes, whose origin was set to a final sensor adhered to the upper incisors (UI), thus correcting active articulator movement for head movement.

2.2. Data manipulation

For each instance of a word-final coronal stop, the TT position on the inferior-superior axis was isolated across a suitable local interval (~0.3s before and after). This TT trajectory was then fitted with a cubic spline for smoothing, and the precise time and TT height at key points on the spline were extracted as illustrated in Fig. 1.

Figure 1: Diagram illustrating key points for speaker-normalised measure of TT raising.



T is the TT height maximum corresponding to raising for a coronal stop. A and B were defined at TT height minima immediately preceding and following T respectively, representing adjacent articulatory targets. For each T, the distance from line AB to T (*h*) was taken and redefined as a proportion of raising from line AB to a speaker-specific maximum TT height MAX (*H*), which corresponds to the highest recorded TT height in a token from that speaker. This proportional measure, 'TT raising' (*h*/*H*), is operationalised as a speaker-normalised value to quantify the degree of effort expended, and thus magnitude of lenition.

3. RESULTS & DISCUSSION

3.1. Acoustics vs. articulation

It is well understood that the acoustic signal does not always fully reflect details of articulatory movement. An example of this is covert TT raising in apparent

CSD. Table 1 shows how instances of no TT raising (≤ 0mm from line AB) only make up a small portion of coronal stops in each grammatical class.

Table 1: Audible stops, inaudible with TT raising, and inaudible without raising.

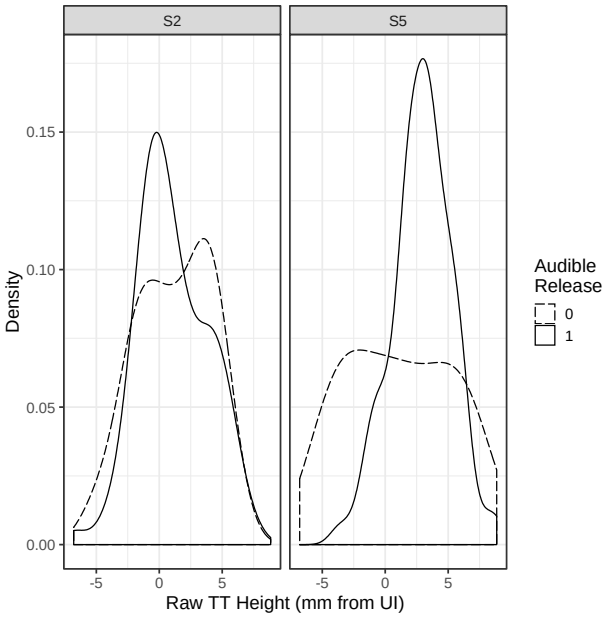
	Audible	Inaudible		Total
		+ Raising	- Raising	
Mono	123 (79%)	29 (19%)	4 (3%)	156
Complex	139 (72%)	42 (22%)	11 (6%)	192
Semi	13 (93%)	1 (7%)	0 (0%)	14
Total	275 (76%)	72 (20%)	15 (4%)	362

In the current data, the expected morphological conditioning on CSD rate does not obtain. This is very likely to be a result of the sample size, which is much smaller than is possible in a non-articulatory study. The issue is compounded by the requirement to discard word-final coronal stops with adjacent coronal segments, which constitute some of the most favourable conditions for CSD.

3.2. Individual Differences

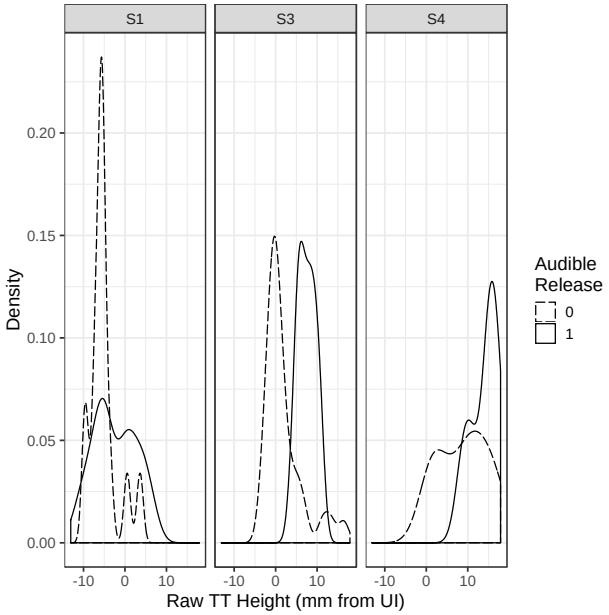
There is doubt from some [2, 13] that CSD is a categorical phonological process at all. Under this view, articulatory zeroes can be interpreted as one end of a continuum of lenition. Certainly, Fig. 2 shows raw TT height distributions from two speakers who seem to show the kind of unimodality this would predict.

Figure 2: Distribution of raw tongue tip heights in Speakers 2 and 5.



On the other hand, categoricity in CSD need not manifest itself as the complete absence of articulatory movement. Fig. 3 shows raw TT height distributions from the remaining three speakers whose profiles are more bimodal.

Figure 3: Distribution of raw tongue tip heights in Speakers 1, 3 and 4.



Of particular interest in Fig. 3 are Speakers 3 and 4, whose entire lower end of TT height is populated with inaudible coronal stops. This suggests that the speakers have an undershot [t] allophone, and inaudible stops under the higher peak are a result of gradient phonetics. Almost all of Speaker 1's inaudible stops have a low TT height, which could be interpreted as evidence that this kind of allophony can exist primarily in the articulatory domain and need not result in audible CSD categories.

3.3. Systematic variation in lenition

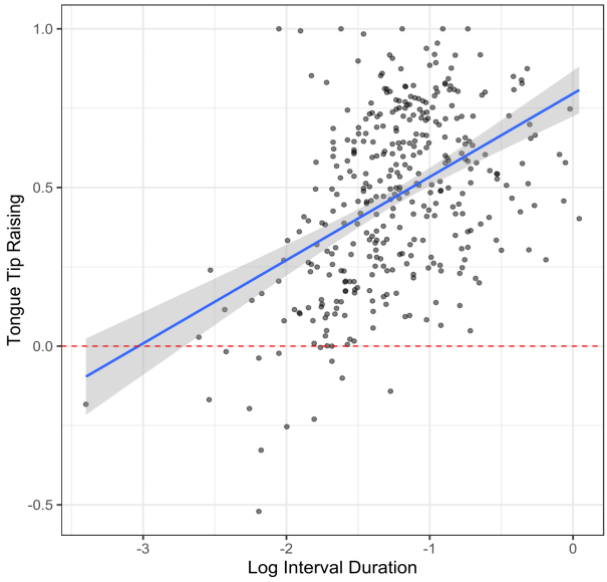
While articulatory data is useful for shedding light on the presumed categoricity of a phenomenon like CSD, we can also explore how the articulatory detail varies in a gradient dimension.

Table 2: TT raising predicted by mixed-effects linear regression: fixed effects.

	Estim.	Std. Err.	DF	t Value
(Intercept)	0.892	0.074	21.4	12.058
logInterval	0.308	0.028	351.6	10.893 ***
taskSemdiff	-0.048	0.050	94.8	-0.966
taskScript	-0.047	0.041	125.7	-1.169
taskWdList	-0.300	0.051	95.1	-5.866 ***
Zipf	0.004	0.006	30.0	0.624
t/dT	0.030	0.040	67.7	0.765
gramMono	-0.072	0.036	44.2	-2.024 *
gramSemi	-0.031	0.069	143.6	-0.455

Table 2 shows fixed effects from linear regression predicting TT raising, with random intercepts for Speaker and Word. Unsurprisingly, there is a strong effect of interval duration such that shorter time between adjacent articulatory targets A and B results in significantly less tongue tip raising. This correlation is shown in Fig. 4. Tokens below the dashed line (line AB), where no tongue tip raising was observed, also seem to occur most frequently when a speaker has a shorter interval to produce a stop.

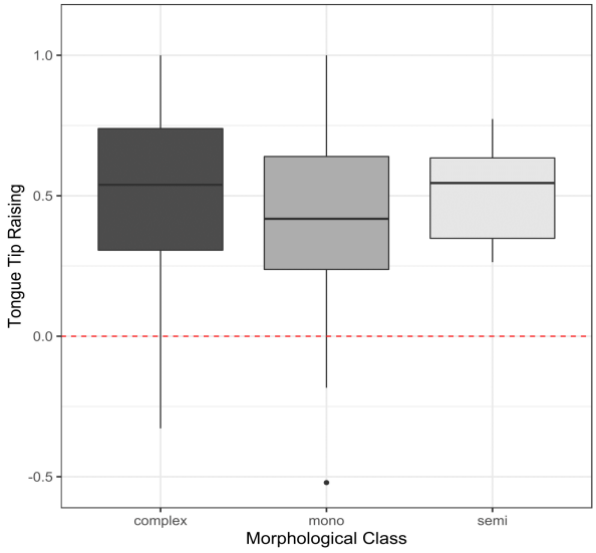
Figure 4: Magnitude of TT raising across interval durations.



One surprising result from Table 2 is that speakers show less TT raising – more lenition – when performing a wordlist task than when providing directions for a map task. If we expect lenition phenomena to be flouted in more formal styles, and the wordlist draws the most attention to speech, we would expect the most TT raising in this task. However, from an information theoretic perspective, a speaker participating in a dyadic map task experiences the greatest pressure to communicate clearly, while the wordlist exerts the smallest amount of this pressure.

A final interesting result in Table 2 concerns morphological class. While Zipfian lexical frequency shows no significant effect on TT raising, there is a marginally significant difference between complex words and monomorphemes such that monomorphemes show slightly less tongue tip raising. Fig. 5 shows distributions of TT raising in each morphological class. Tokens below the dashed line exhibit no TT raising. This is a similar result to what Purse and Turk [8] observed for Southern Standard British English. It is noteworthy because it shows a morphologically conditioned lenition effect in the same direction as the robustly attested morphological conditioning on the rate of CSD. However, this kind of morphological conditioning on gradient phonetics cannot easily be accounted for under strict modularity.

Figure 5: Magnitude of TT raising for coronal stops in words of different morphological class.



4. CONCLUSIONS

The presumption of categoricity in CSD is deeply flawed, and it is clear that true articulatory zeroes actually only constitute a small proportion of inaudible stops. However, if we extend our understanding of categoricity beyond just instances of true articulatory zeroes, some individuals exhibit a covert allophony in terms of the raw TT height achieved for coronal stops. This appears to be highly correlated with CSD, but not deterministically. It remains a challenge to collect sufficient articulatory data to explore the relationship between this kind of allophony and the factors that have been observed to influence rates of CSD in the past. Specifically, predictions about the behaviour of different morphological classes in terms of categoricity and true articulatory zeroes are unresolved. Further, significant effects of articulatory interval, task, and a marginally significant effect of morphological class on TT raising suggest that the articulatory detail of coronal stop production varies systematically. This may pose a problem for many classic views of speech production that prohibit grammatical conditioning in the domain of gradient phonetics. Finally, there remains the crucial question of how the learner can acquire something that they may not be able to directly perceive.

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