AN ACOUSTIC ANALYSIS OF VOICING IN AMERICAN ENGLISH DENTAL FRICATIVES[1]

Bridget Smith
The Ohio State University

Abstract

In this study, an acoustic analysis of the dental fricatives as produced by American English speakers from the Buckeye Corpus (Pitt et al. 2006) reveals that the dental fricatives are subject to variation in voicing based on phonetic environment, much more than is usual for a pair of phonemes whose phonological distinction is based on voicing, confirmed by a comparison with the voicing of /f/ and /v/. The results of the study show that voicing (presence or absence of glottal pulses) for /θ/ and /ð/ is not predictable by phoneme in conversational speech, but it is more predictable based on voicing of surrounding sounds.

[1] This acoustic analysis was originally intended to be included in Smith 2009, "Dental fricatives and stops in Germanic." However, the editors and reviewers decided, and rightly so, that there were actually two papers there, so the acoustic analysis was removed and has been referred to as Smith 2007, "The seeds of sound change don't fall far from the tree," unpublished ms. While it has been my intention for some time to replicate the original study, introducing a number of new measurements and methods of analysis, while verifying the original measurements, this paper has sat on a back burner, still unpublished. While I still intend to perform such a reanalysis and submit it to a peer-reviewed journal, under whose scrutiny it will no doubt improve greatly, I submit this early version to the OSU Working Papers so that it may be more easily accessed by those who have expressed interest in it, for those who cannot wait for the next version to be published, and for those who have yet to discover it.

Bridget Smith. An acoustic analysis of voicing in American English dental fricatives. *OSUWPL*, Volume 60, Spring 2013, 117-128.

1. Introduction

The voiceless dental fricative (IPA /θ/) and the voiced dental fricative (IPA /ð/) are relatively understudied in comparison to other sounds. They are perceptually weak and easily confusable with /f/ and /v/. Because the voiced phoneme /ð/ appears word-initially in function words and word-finally in verbs (where the voiceless phoneme /θ/ does not appear), it is difficult to create psycholinguistic tasks in which the salience of the contrast can be measured. And because /θ/ and /ð/ may vary along multiple acoustic dimensions at once, forced choice tasks along a single dimension may not be particularly informative. Categorical replacement of /θ/ and /ð/ by /f/ and /v/ or /t/ and /d/ in certain dialects and sociolects has been studied, such as in AAVE (Wolfram 1970, 1974, among others) or London Cockney English (Wells 1982; Hughes, Trudgill & Watt 2005, among others). Polka, Colantonio, & Sundara (2001) found that English-speaking infants were less able to distinguish between /d/ and /ð/ than between /b/ and /v/, which suggests that the variation in production of the dental fricative which infants are exposed to overlaps to some extent with the alveolar (or dental) stop, so that they are unable to interpret a phonemic pattern until they are much older. A number of studies have looked at acoustic measurements to distinguish place of articulation among various groups of fricatives, and have either avoided /θ/ and /ð/, or were least successful in distinguishing /θ/ from /f/.

Stevens et al. (1992) show that the presence or absence of phonation is the acoustic parameter that best distinguishes between voiced and voiceless fricatives, and they are by no means alone in this judgment. See, e.g., Pirello, Blumstein, & Kurowski (1997). Denes (1955), however, demonstrated earlier that duration of a word-final fricative, and comparatively, the duration of the preceding vowel, could be manipulated to give the impression of voicing for longer vowels and shorter fricatives, and of voicelessness for shorter vowels and longer fricatives. Raphael (1972) confirmed these findings, and noted that “when the voicing characteristic is cued by vowel duration, perception is continuous rather than categorical” (1296). Pirello et al. (1997) say also that the production aspect of voicing is itself continuous, in that “the feature voicing in fricatives is manifested in a continuous way and as such cannot be characterized in terms of a binary distinction relating to the presence or absence of glottal excitation” (3754). Due to the complex nature of producing a voiced fricative, either voicing or frication may be lost during production: too little supraglottal pressure and frication fails, but if the supraglottal pressure is not sufficiently less than the subglottal pressure, voicing will fail. In addition, coarticulation frequently results in gestural overlap, with voicing (or the lack thereof) spreading from neighboring segments. It is for these reasons that a binary presence or absence of glottal pulses is insufficient to discriminate between voiced and voiceless fricatives. The amount of voicing overlap and the issue of duration is greatest for medial and final fricatives, but Pirello et al. (1997) achieved 93% accuracy classifying word-initial /s/ and /z/, and /f/ and /v/ from read speech. Using Stevens et al.’s (1992) rubric, in which the amplitude of the first harmonic of the fricative was compared to that of the following vowel, the fricatives were categorized as voiced and voiceless. The voiceless label was assigned to tokens with 10 dB or greater difference in amplitude. They argued that presence of glottal excitation present in at least 30 ms of either the beginning or the end of the fricative was enough to correctly distinguish voiced from voiceless fricatives; although, they did not examine /θ/ and /ð/.

These previous studies, and others, have relied upon lab-produced read speech. While this allows researchers to exert some measure of control over variation, and creates tokens that can be easily compared across speakers, it does not give us a real picture of what these fricatives look like in conversational speech, and does not give an accurate picture of how these sounds might be discriminated by language users. Accumulated anecdotal observations provided the questions for this study: How strong is the voicing distinction between /ð/ and /θ/ in conversational speech? And is this distinction based on phonation, or do duration, intensity, or even manner of articulation play a greater role in conversational speech? When does voicing occur? What phonetic factors may be related to voicing? Does the phonological description of 'phoneme' match up with the phonetic realizations of /ð/ and /θ/? A parallel examination of /f/ and /v/ was conducted to find out what measures might be significant in distinguishing the voiced from the voiceless segments, and to provide a control group for comparison.

2. History

Both the voiced and voiceless dental fricatives are represented orthographically in English by the digraph <th>. /θ/ usually occurs word-initially or word-finally, and can occur medially in loanwords and certain compounds. /ð/ occurs word-initially only in function words such as articles and demonstratives, rarely in word-final position in certain derivational words such as *bathe* or *teethe*, and occurs in medial position in a greater number of words. There are a few minimal pairs, such as *thigh* and *thy, either* and *ether,* and *teeth* and *teethe*, and some near-minimal pairs such as *breath* and *breathe.* Despite the existence of at least one minimal pair in all positions, the contrast between these phonemes carries little, if any, functional load. The minimal pairs that exist cannot be used in the same position in a sentence, belonging generally to different classes of words.

This distribution is easily explained through the historical development of these sounds. In Old English, the *thorn* <þ> and *edh* <ð> characters interchangeably represented both the voiced and voiceless variant, which were at that time in complementary distribution. It is generally assumed that thorn or edh in initial and final position was voiceless, while between voiced sounds, it was voiced. /f/ and /v/ (and /s/ and /z/) had a similar distribution. Early on in Middle English, /f/ and /v/ (and /s/ and /z/) became phonemic, due to a confluence of factors, not least of which was the introduction of large numbers of loanwords containing these sounds in contrastive positions. Late during the Middle English period, it was noticed that there were two <th> variants, presumably a voiced and a voiceless phoneme (Bullokar 1580). Function words such as *the, that, this, then*, etc., are assumed to have begun with a voiceless dental fricative in Old English, but their Modern English counterparts have become voiced. Because they are often unstressed and not discrete from adjacent words, they are more likely to assimilate to surrounding voiced sounds. Another possible contributing factor is that the high frequency of these function words may have allowed a large amount of variation, which became generalized as a voicing contrast. Note that the phonologization of these sounds occurred after the paradigm leveling that reduced the number of different forms of these function words. For example, the definite article *the* was inflected for case, gender, and number in Old English, yielding approximately 12 distinct forms of this word. The increased frequency of single forms of certain types of words may have created the situation that allowed reduction and variation of these high frequency words that now carry much less grammatical information. Word-final /ð/ also appeared in late Middle or Early Modern English, with the loss of verb endings stranding the medially-voiced fricative at the end of the verb. The greatest number of instances of /θ/ that occur outside of the original conditioning environment are in more recent loanwords such as *author, arithmetic,* and *arthritis*, and in forms that have undergone some kind of analogy or reanalysis, such as *Arthur* or *anthem*. /v/ and /f/ have followed a similar trajectory, with fossilization of the original conditioning environment in many words, but with a much greater number of minimal pairs from borrowing, though the contrast is arguably less than that of /s/ and /z/. Therefore, it stands to reason that /v/ and /f/ are the closest point of comparison to /ð/ and /θ/.

3. Methods

Eight talkers (four men, four women) were selected from the Buckeye Corpus (Pitt et al. 2006), which is a body of 40 sociolinguistic interviews with Ohio residents. After subsequent analysis, one of the male talkers' data were excluded from this analysis because of speech differences possibly resulting from a head injury. From approximately 15 minutes of conversational speech per talker, around 400 /ð/ and /θ/ and 300 /v/ and /f/ tokens were measured altogether. Between 15 and 25 /θ/ tokens were measured from each speaker, 25-45 /ð/ tokens, 11-30 /f/ tokens, and 10-35 /v/ tokens. Additional tokens were marked as assimilated or deleted, but not included in the measurements.

In Praat (Boersma & Weenink 2007), an acoustic analysis software, intervals were measured for the duration of frication of /θ/, /ð/, /f/, and /v/. Average intensity of these periods was also measured. Because of the variability of conversational speech, and the greater degree of coarticulation, no single uniform cue existed for determining the beginning or end of the fricative. Obvious frication was used as a marker, where it was present, generally in voiceless tokens. In voiced fricatives, either frication or reduced amplitude of formants as compared to surrounding vowels was a reliable marker. In some cases, /ð/ could be perceived in the speech signal, but not identified by characteristics in the waveform or spectrogram. In these and other cases in which the sound was completely unable to be differentiated from surrounding sounds, it was marked as assimilated or deleted. The beginning and ending of periods of voicing within the fricative were also measured. Intervals were marked as voiced if periodicity in the waveform and/or presence of a voice bar in the spectrogram indicated regular glottal pulses. To minimize confusion with the phonological feature [+voice], these are described as having *voice bar*. A measure of voicing was then created by taking the percentage of the duration of the fricative in which a voice bar could be found. The immediately preceding and following segments adjacent to each fricative, and whether or not they were voiced, were marked and noted. Neighboring segments were only classified as voiceless if there was no periodicity in the waveform for more than 50% of the segment. A neighboring pause also counted as a voiceless segment because the vocal folds were not vibrating.

A subset of four talkers was selected for an additional analysis examining manner of articulation of the dental fricatives as well. The author examined the waveform and spectrogram, and listened to each token to arrive at the manner judgments. A description of characteristics used to identify each manner is given in the appendix. A second trained transcriber also gave manner judgments for each segment. For the fewer than 5% of the judgments that did not match between the two transcribers, these were then judged in tandem and an appropriate label agreed on. The majority of cases were approximants or flaps that could not be decided on, and without any concrete way of separating these two, the categories were combined into one.

4. Results

The results of the manner judgments are listed in Table 1. /ð/ was realized as a voiced fricative only 20.3% of the time. 23.4% of the time it was realized as a nasal, 18.4% as a stop, and 15.4% as an approximant or flap. /θ/, on the other hand was realized as a voiceless fricative 55.1% of the time, but was also realized as a stop 15.9% of the time, and as a voiced fricative 10.1% of the time. Because of the lack of contrast in manner at the interdental/dental place of articulation, /ð/ and /θ/ are free to vary in this way, though there is much more variation than one might expect.

Table 1: Manner judgments of dental fricatives

Manner of articulation	**edh /ð/**	**theta /θ/**
affricate	0.013	0.029
approximant/flap	0.152	0.043
deletion/vowel	0.095	0.015
voiced fricative	0.203	0.101
voiceless fricative	0.088	0.551
fricative+approximant	0.006	0.0
fricative+stop	0.019	0.058
lateral	0.006	0.0
nasal	0.234	0.015
stop	0.184	0.159
stop+lateral	0.0	0.029

Tokens which were completely assimilated or deleted were not included in the acoustic measurements, because they could not be segmented away from the following sounds. An additional 2 /v/ tokens and 5 /θ/ tokens were removed as outliers, having durations greater than 3 standard deviations from the mean, and were greatly lengthened while the interviewee was thinking of what he/she wanted to say next.

Measurements of absolute duration, as in Figure 1, reveal a great amount of overlap, which is unsurprising for conversational speech. What is notable, however, is that /ð/ and /θ/ pattern very similarly, while /f/ and /v/ show a bimodal distribution, with /f/ having a shorter duration (median 11 ms) than /v/ (median 35 ms), which is entirely the opposite pattern from we would expect. /ð/ and /θ/, while having a similar distribution to each other, also have the majority of tokens clustered around a very short duration, with half the tokens of both being less than 15 ms. These tokens are initial, medial, and final, and in a variety of mono- and polysyllabic words with varying stress. Many neighboring segments were not vowels, and many vowels were reduced to the point of deletion. Calculating the fricative duration relative to surrounding vowel duration did not make sense in this case. Measures of intensity posed the same challenges due to the varied nature of conversational speech. As can be seen in Figure 2, the distribution of average intensity measured over the duration of each fricative is very similar for /ð/ and /θ/ as well as /f/ and /v/, though /f/ has a slightly lower average intensity than /v/.

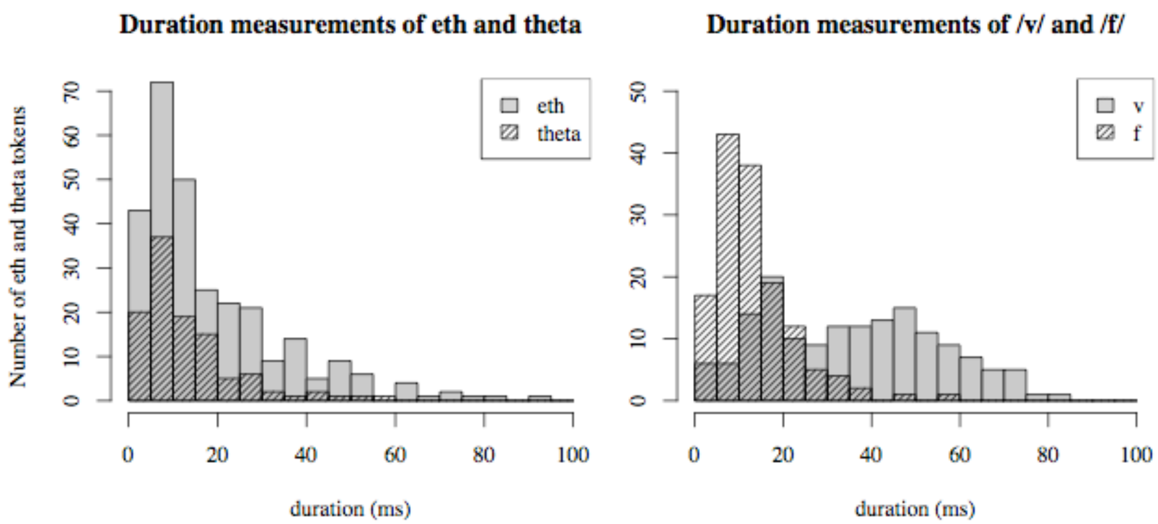

Figure 1: Duration of /ð/ and /θ/ (histogram on the left) and of /f/ and /v/ (on the right).

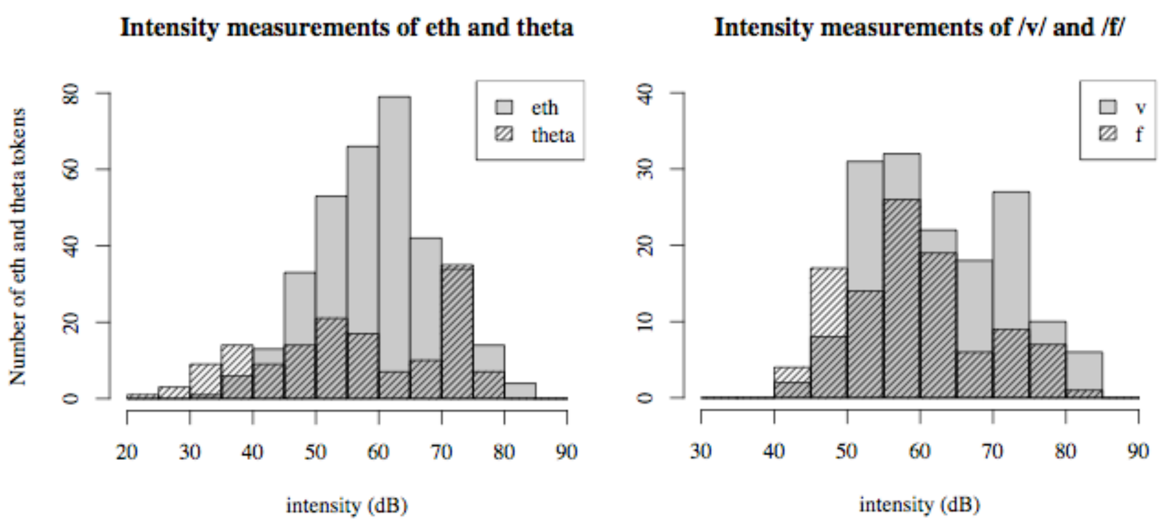

Figure 2: Average intensity of /ð/ and /θ/ (histogram on the left) and of /f/ and /v/ (right).

Because the overall duration measurements were more varied, and generally shorter than those in either Pirello et al. (1997) or Stevens et al. (1992), looking for 30 ms of voicing at either end of the fricative did not make sense. More than half of the fricatives were shorter than 30 ms overall. Because the tokens were not taken from CV sequences, but rather had very different environments, the measurement from Pirello et al. (1997) and Stevens et al. (1992), comparing the intensity of the first harmonic between the fricative and following vowel was not practical. Instead, the appearance of voice bar (periodicity of the waveform) was measured for each fricative interval, and taken as a percentage of the total duration of the fricative, as in Figure 3. The distribution for /f/ and /v/ appears bimodal, although there is a large amount of overlap. The majority of /f/ tokens are clustered below 20% voiced, while the majority of /v/ tokens are greater than 90% voiced. Again, /ð/ and /θ/ do not pattern exactly the same way as /f/ and /v/. There are two distributions, but not separated by phoneme. There is one distribution composed of both /ð/ and /θ/ tokens, clustered around 10-30% voiced, and another substantial cluster of 90-100% voiced tokens, composed primarily of /ð/ tokens, though including a few /θ/ tokens as well.

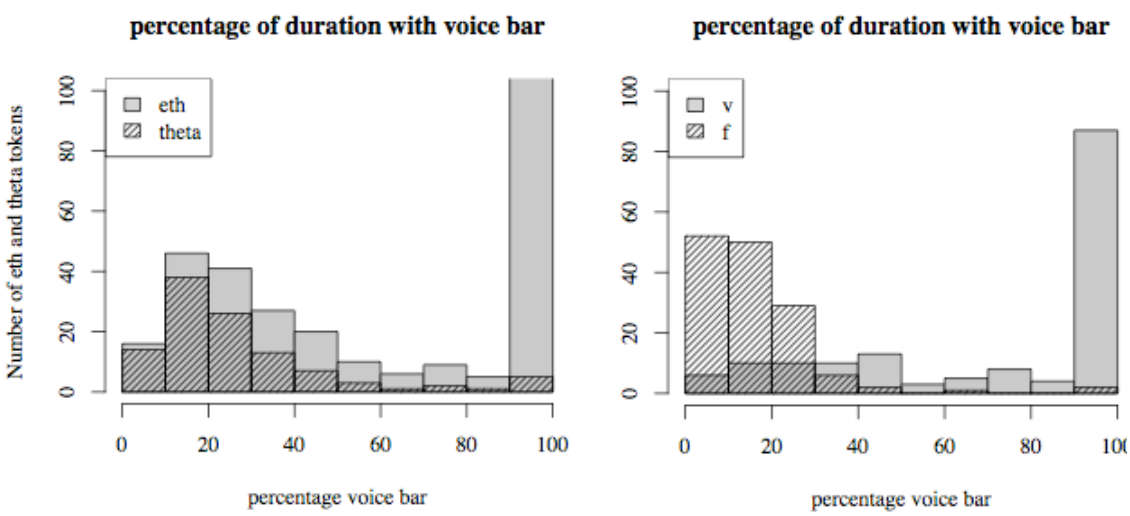

Figure 3: Percentage of the duration of the fricative that contained voice bar, with /θ/ and /ð/ on the left, and /f/ and /v/ on the right.

Yet somehow listeners are able to understand conversational speech. Because /ð/ and /θ/, and to a lesser extent, /f/ and /v/, maintain a similar pattern to their historical distribution, we might expect the voicing to pattern the same regardless of whether we separate the results by phoneme or by environment (that is, whether there is an adjacent voiceless sound, or if the segment is surrounded by voiced sounds). However, when we plot the same voice bar measurements as in Figure 3 by environment, as in Figure 4, a new pattern emerges. The dental fricatives develop a bimodal distribution, with predominantly voiceless sounds clustered on the left and predominantly voiced sounds on the right, distinguished not by phoneme, but by whether they were surrounded by voiced sounds or had a voiceless sound (including a pause) either preceding or following. The distribution of labio-dental fricatives shows a similar though somewhat murkier pattern, where this analysis appears to create more overlap, rather than reducing it.

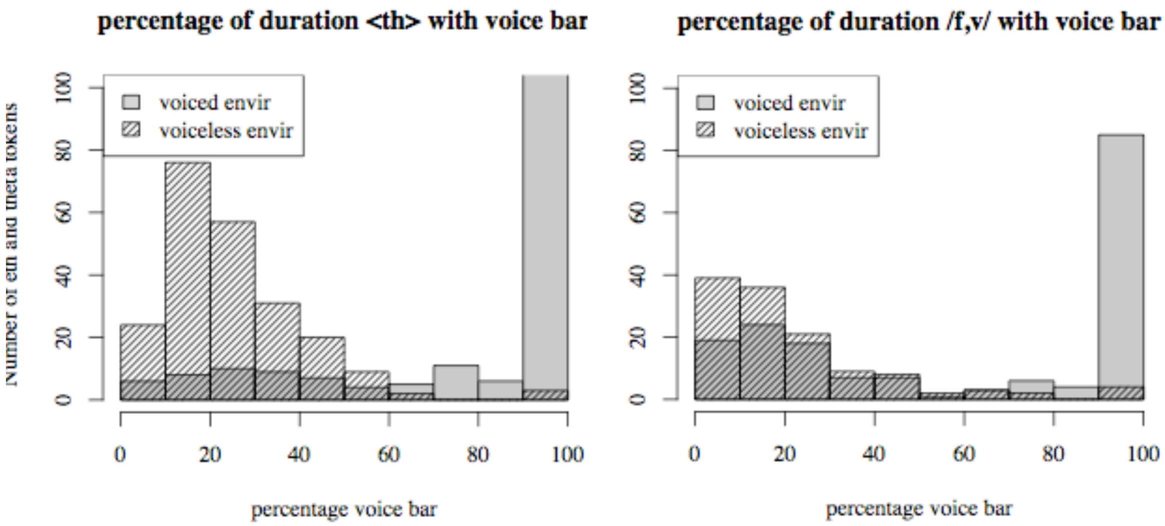

Figure 4: Percentage of the duration of the fricative that contained voice bar, with /θ/ and /ð/ combined on the left, separated by whether or not an adjacent segment was voiceless, and /f/ and /v/ combined on the right, also separated by voicing of adjacent segment.

Because the categories of phoneme and of environmental voicing largely overlap for these sounds, a partial correlation statistic was run on each of these data sets in order to determine how much variation was accounted for by phoneme, excluding that accounted for by environmental condition, and how much was accounted for by environmental condition, excluding that accounted for by phoneme, as in Table 2. Table 3 shows, by way of comparison, the results of a normal correlation of percent voiced by phoneme and by environment, separately.

Table 2: Partial correlation comparing variation accounted for by phoneme and environment, "partialing out" the variation accounted for by the other factor (environment and phoneme, respectively).

	r of voicing by ***phoneme***, with environment partialed out	**r** of voicing by ***environment***, with phoneme partialed out
dental fricative	0.4494	0.7661
labio-dental fricative	0.7186	0.4632

Table 3: Correlation of voicing and environment, and of voicing and phoneme.

	r of voicing by ***phoneme***, regardless of environment	**r** of voicing by ***environment***, regardless of phoneme
dental fricative	0.3666	0.7428
labio-dental fricative	0.7403	0.5157

The results of the correlation and partial regression show that phoneme category better accounts for the percentage of the duration that has voice bar in labio-dental fricatives, such that /v/ has generally more voicing, and /f/ less. But environment, that is, whether surrounding sounds are voiced, does a better job of accounting for percentage of voicing in dental fricatives, regardless of phoneme.

5. Discussion

The results of this investigation seem to indicate that the voicing contrast between the dental fricatives does not hold up well in conversational speech, even less well than /f/ and /v/, which are also highly variable. Duration and intensity are also not reliable measures of phonemic voicing in conversational speech. In fact, the very environments which conditioned voicing of the Old English dental fricative are more or less the same environments that predict voice bar in the modern dental fricatives. Even the "voiced" phonemes in function words can be produced as voiceless, although these are the same words that we assume were at least partially responsible for the phonologization of the voicing contrast. These results call into question whether the distinguishing feature between the two phonemes is actually voicing, or if there are some environments in which the contrast is neutralized. Because there is little to no competition in the interdental place of articulation, manner is free to vary, and indeed only 55% of the tokens of /θ/ and 29% of /ð/ that were analyzed in this experiment were realized as canonical fricatives; therefore, manner is also not a reliable indicator.

One thing that can be said for certain is that the variation of /ð/ occupies a much larger acoustic space, and encompasses that of /θ/, as illustrated in figures 1-3 for duration, intensity, and voicing, but also in place and manner, especially as it assimilates more readily to surrounding sounds, as in the greater number of tokens that were assimilated or deleted in this study. This raises some interesting questions. If the canonical forms are reported to be fairly confusable, but the conversational forms are even more variable and overlapping, how is it that we are able to distinguish them in speech? Or, because of the very low functional load carried by this contrast, do we even need to distinguish them? If voicing is predictable from environment, would it not be likely that listeners would have difficulty reconstructing an underlying form? Future studies are needed to explore perceptual aspects of and contrast or lack thereof in the dental fricatives.

References

Boersma, Paul & David Weenink. 2007. Praat: Doing phonetics by computer (Version 4.5.14) [Computer program]. Retrieved February 2007, from [http://www.praat.org/].

Bybee, Joan, & Paul Hopper. 2001. Editors. *Frequency and the emergence of linguistic structure.* Amsterdam: John Benjamins.

Dalen, Arnold. 2002. "Sources of written and oral languages in the 19th century". In *The Nordic Languages: An international handbook of the history of the North Germanic languages.* Vol 2. Ed. by Oskar Bandle, Kurt Braunmuller, Ernst Hakon Jahr, Allan Karker, Hans-Peter Naumann, & Ulf Teleman. Berlin: DeGruyter. 1406-1418.

Hughes, Arthur, Peter Trudgill, & Dominic Watt. 2005. *English accents and dialects: An introduction to social and regional varieties in the British Isles*. 4th ed. London: Trans-Atlantic Publications, Inc.

Maddieson, Ian, & Kristin Precoda. 1990. UPSID-PC *The UCLA Phonological Segment Inventory Database.* (Data on the phonological systems of 451 languages, with programs to access it.) Accessed from [http://www.linguistics.ucla.edu/faciliti /sales/software.htm]

Pirello, Karen, Sheila E. Blumstein, & Kathleen Kurowski. 1997. "The Characteristics of Voicing in Syllable-Initial Fricatives in American English". *Journal of the Acoustical Society of America* 101.3754-3765.

Pitt, Mark A., Laura Dilley, Keith Johnson, Scott Kiesling, William Raymond, Elizabeth Hume, & Eric Fosler-Lussier, comps. 2006. *Buckeye Corpus of Conversational Speech*. (1st release) [www.buckeyecorpus.osu.edu] Columbus, Ohio: Department of Psychology, Ohio State University (Distributor).

Polka, Linda, Connie Colantonio, & Megha Sundara. 2001. "A cross-language comparison of /d/ - /ð/ perception: Evidence for a new developmental pattern." *Journal of the Acoustical Society of America.* 109(5):2190-2201.

Raphael, Lawrence J. 1972. "Preceding vowel duration as a cue to the perception of the voicing characteristic of word-final consonants in American English." *Journal of the Acoustical Society of America.* 51:1296-1303.

Smith, Bridget J. 2007. "The seeds of sound change don't fall far from the tree". Unpublished ms. presented at *OSU Colloquium Fest*, Nov. 9, 2007.

Smith, Bridget J. 2009. "Dental fricatives and stops in Germanic." In Dufresne, Dupoux, & Vocaj (eds.), *Historical Linguistics 2007. CILT 308*. 19-36. Amsterdam/Philadelphia: John Benjamins.

Stevens, Kenneth N., Sheila E. Blumstein, Laura Glicksman, Martha Burton, & Kathleen Kurowski. 1992. "Acoustic and Perceptual Characteristics of Voicing in Fricatives and Fricative Clusters". *Journal of the Acoustical Society of America.* 91: 2979-3000.

Wells, John C. 1982. *Accents of English 2: The British Isles*. Cambridge University Press. 1982.

Wolfram, Walt. 1970. "Some illustrative features of Black English." Workshop on Language Differences. Coral Gables, FL, February 1970

Wolfram, Walt. 1974. *Sociolinguistic aspects of assimilation: Puerto Rican English in New York City.* Arlington, VA: Center for Applied Linguistics.

Appendix: Characteristics of manner of articulation

Criteria used for manner judgments presented in Table 1.

(A) Voiceless fricative: Characterized by aperiodic noise, sometimes forming a diamond or triangle shape in the waveform as intensity increases over the course of the fricative. Because /ð/ and /θ/ are very quiet, the aperiodic noise may maintain a very low intensity throughout. It sounds like a traditional <th> sound, as in *thing*. There may be one or more quiet bursts, but if the frication leading up to and following the burst are of a similar character, and the burst is quiet, and the segment sounds like a fricative, it is labeled as a fricative rather than a stop. Bursts may occur in fricatives as the oral air pressure builds up behind the constriction and is released. This can happen if the lungs are sending out a little too much air to fit through the narrowed constriction. Large bursts occur (and may be labeled as a stop) if the constriction is too narrow and the air pressure too high, so that the air gets really backed up and the constriction acts as a (leaky) closure. See section (C) on stops.

(B) Voiced fricative: Sounds like <th> in the word *then* or *breathe*. There should be frication in the higher frequencies, visible as aperiodic noise in the waveform, as well as regular periodicity indicating voicing for most of the duration. Sometimes the frication may be quiet, and only barely distinguishable from background noise, but there should be at least some fuzziness (aperiodic noise) in each period. Though there will be regular voicing, the waveform will have much less intensity than nearby vowels or approximants, and the spectrogram will not have clear formants, especially above F3.

(C) Stop: Noted where there is a (larger, usually audible) burst, with or without voicing, and with or without aspiration. Usually there will be some period of closure (with or without voicing) before the burst, followed by aspiration or frication. This will sound like it has a much more aggressive onset that that of a regular fricative. There may be little or no aspiration after the fricative (as in a short-lag or voiced stop) or there may be aspiration and/or frication as in an aspirated stop. (But if the frication is very strong and/or long, it may be labeled as an affricate.)

(D) Approximant: A dental fricative realized as an approximant may sound vaguely /l/ -like. Formants may be clear or faint, but they have noticeably reduced amplitude relative to surrounding vowels. There should be no frication noticeable in the waveform or spectrogram. Flaps look like approximants that have slightly shorter duration and reduced amplitude, and especially unclear or absent formants, but there are many tokens that are ambiguous. Flaps are also labeled as approximants because there is no good way of distinguishing between them.

(E) Vowel: A dental fricative may be realized as a vowel, usually a /ə/ or /□/ type sound. The waveform is (nearly) indistinguishable from surrounding vowel sounds, and there are very clear formants, also (nearly) indistinguishable from surrounding vowels. The difference between the vowel and approximant is one of amplitude. Generally, approximants have reduced amplitude relative to vowels, and fainter formants. If there is no decrease in amplitude, it is a vowel. If no trace of the dental fricative can be heard, then it is marked as a deletion. If there is a change in the vowel quality corresponding to the percept of a dental fricative, then the segment is labeled as a vowel.

(F) Nasal: It has antiformants, reduced amplitude, and is often next to another nasal. The nasality is clear in the spectrogram, but is also audibly obvious. If the combined segment is as short as a single segment, the dental fricative may just be deleted. If the nasal is long, the dental fricative is assimilated and realized as a nasal.

(G) Lateral: While approximant realizations may sound somewhat /l/-like, segments marked as laterals are obvious /l/s. These usually occur as complete assimilations to neighboring segments. If the original /l/ plus dental fricative as /l/ looks longer than a single segment, the dental is realized as a lateral. If the combined segment is as short as a single segment, the dental fricative may just be deleted.

(H) Affricate: A combination of a stop+fricative

(I) Mixed bag: If the sound has two distinct manner realizations, such as fricative+stop or fricative+approximant, both are noted.