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1 Introduction

This paper reports results from a study addressing the effect from prosodic boundaries on articulation of domain-final consonants in a moribund dialect of American English spoken on the Iron Range of Northern Minnesota.[1] Previous research on the dialect found that Iron Range English (IRE) exhibits devoicing of final fricatives and stops ("bus" for "buzz," and "cap" for "cab"), but there has not been a description of the acoustic correlates of this devoicing (Linn 1988). This study examines acoustic data from four older speakers of IRE, testing for the presence of devoicing, and studying whether it can be attributed to category neutralization, or whether the effect might be attributed to prosodic effects at the level of articulatory gestures, as was suggested by Bauer (2004). Results demonstrate that boundary effects may constitute a locus of variation across dialects of American English.

2 Background

The Iron Range extends 110 miles in the northeast area of Minnesota, above Lake Superior, following along the way a cluster of ridges that historically held wide ribbons of super-rich iron ore. When ore was discovered in the late nineteenth-century, the area's population grew rapidly in order to meet demand for mining labor ("Geology" 1887, Jennings 1894, Underwood 1981). Sirjamaki (1940) noted an ethnically diverse but rapidly homogenizing population and reported that the origins of early Iron Range inhabitants were predominantly Finnish, Cornish, English, French-Canadian, Swedish, Slovenian, Croatian, and Polish. Despite the variety of ethnicities and languages of the early inhabitants, by 1910 about half of the Iron Range miners could speak English, and by the mid-1930s as much as one third of the Iron Range population had intermarried across ethnicities (Underwood 1981, Sirjamaki 1940).

Among the members of the Iron Range community and elsewhere in Minnesota, there is a general folk belief that the Iron Range constitutes a unique dialect enclave. There are several popular pamphlets and books at-

[1] This paper is based on results reported in Bauer (2005).

testing to the uniqueness of the dialect, including several volumes of Mike Kalibabky's *Hawdaw Talk Rayncher* (1979, 1996).

There are only a handful of studies of Iron Range English. Underwood (1981) examined vowel pronunciation, verb phrase formation, and lexical choice among 12 speakers of Iron Range English, and compared the results to Allen's (1976) results for the rest of Minnesota and to Kurath and McDavid's (1961) results for the Mid-Atlantic and New England regions. Underwood found minimal differences among the speakers of Iron Range English compared to the other datasets but cautioned that he omitted characteristics of consonant articulation, where distinguishing characteristics might be evident.

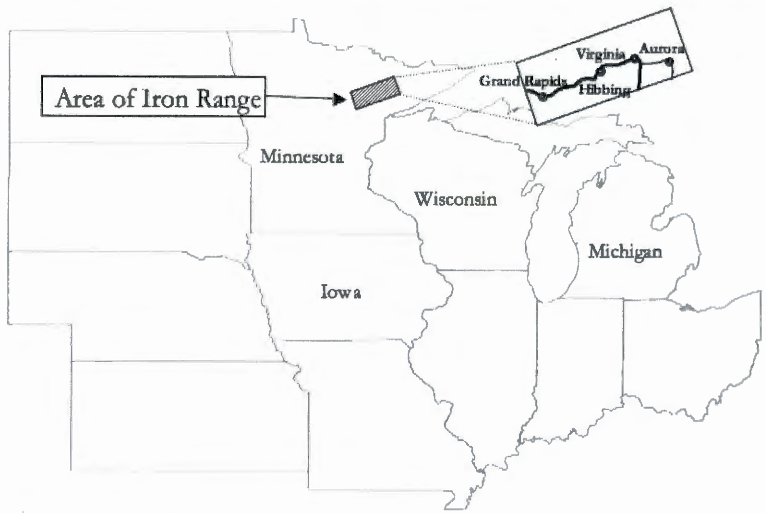

Figure 1: Area and location of Iron Range.

Following Underwood's study, Linn (1988) identified several phonological alternations among consonants in IRE. Among them, Linn reported that IRE exhibits final devoicing of fricatives and stops ("bus" for "buzz," and "cap" for "cab"), "hardening" of nasals ("sink" for "sing"), and "hardening" of interdental fricatives ("dem" for "them). As part of the study, Linn interviewed several generations of Iron Range speakers and noted impressionistically which dialect features were present in the speech.

In an acoustic study, Bauer (2004) examined data of alveolar and labiodental fricatives produced by two older male speakers of Iron Range English to test whether devoicing of fricatives results in neutralization to voicelessness. Results showed that devoiced fricatives exhibit the same amount of voicing as fully voiced fricatives, and that both sets of fricatives exhibit longer voicing durations than naturally voiceless fricatives. The difference between devoiced fricatives and those judged to be voiced is that the devoiced fricatives had significantly longer voiceless frication durations at the end of the segment. Thus, the extra voiceless frication is the likely cue to devoicing.

Interestingly, cases of devoicing were present almost exclusively at the ends of utterances. This was true for both alveolar and labio-dental fricatives. In light of this, Bauer (2004) suggests devoicing is an effect due to prosodic position: At the ends of utterances, the fricated constriction gesture is lengthened while voicing duration is unchanged. The effect is strong enough that, occasionally, voiceless frication is lengthened to the point where fricatives are perceived as devoiced.

A question then arises about other cases of final devoicing in IRE that Linn (1988) reports—namely cases of final stop devoicing. Implicit in Linn's descriptions is that devoicing is a neutralizing process in the dialect, but Bauer (2004) suggests that neutralization is not operative for fricatives. The possibility that there is a lengthening effect based on the position of the fricative in an utterance suggests that suprasegmental effects are the cause of devoicing. Considering this, the prosodic effect observed in the constriction gesture of fricatives may also be present in stops. In this paper, this possibility is tested in an experiment designed to determine whether devoicing of stops and fricatives is a category neutralizing process, or whether effects from prosody induce change in the quality of the segments in Iron Range English.

3 Prosodic Strengthening vs. Neutralization

By "category neutralization" is meant the issue of whether, for example, voiced final stops and fricatives in IRE inherit all the acoustic and articulatory characteristics of voiceless stops and fricatives. In that sense, if the devoicing process is "neutralizing," it renders acoustic contrast between voiced and voiceless segments indistinguishable. Along these lines, by "prosodic effects" is meant the issue of whether segments at certain prominent positions of prosody make the possibility of devoicing more likely. Such positions are also "strong" positions, and they refer to specific points within speech. The boundaries of words are prominent positions, as are the boundaries of groups of words of a particular size, also called "phonological phrases." Positions of even more strength are boundaries of "intonational phrases" (e.g. before a pause, or at places usually marked by a comma in text) and at boundaries of utterances (the ends of sentences).

Generally, when segments are at prominent positions, characteristics of the segments are believed to undergo "strengthening." Research has shown that vowels at positions of greater prosodic prominence are more sonorous and less prone to coarticulation effects, and consonants are more constricted, have longer durations, exhibit less overlap between articulatory gestures, and make more articulatory contact (Fougeron and Keating 1997, Keating, Cho, Fougeron and Hsu 2003, Cho and Keating 2001, Tabain 2003a,b, Cho 2004). A major goal of much of this literature has been to show that the effect of prosodic prominence on segments is consistent across languages. Less important has been to point out differential effects, but a few recent examples do so (Cho and McQueen 2005, Tabain and Perrier 2005, Cho in press). Considering these known cross-linguistic differences in the effect of prosody on articulation, it seems quite possible that such effects may play a role in explaining devoicing in Iron Range English.

4 The Study

The goal of the study was to determine whether neutralization or prosodic strengthening gives rise to the impression of devoicing in IRE. An acoustic experiment was designed to test these possibilities.

4.1 Participants

Four older speakers from two cities on the Iron Range (Hibbing and Chisholm) participated in the study. The average age of the speakers was 79 years. There were two males (M1 and M2), and two females (F1 and F2). Speaker M1 was 67, F1 was 91, M2 was 81, and F2 was 78 at the time of the experiment. Speaker F1 lives in Hibbing, a town of about 18,000 residents. The other speakers live in Chisholm, a town of about 3,000 residents, 10 miles east of Hibbing. All of the speakers have lived on the Iron Range for their entire lives. None of the speakers who participated in this study took part in the study reported in Bauer (2004).

4.2 Materials and Procedure

The experimental materials included fricatives and stops that Linn (1988) reports become devoiced. These are /v,z,ð,b,d,g/. Monosyllabic words ending in these segments were inserted into sentences at each of four prosodic boundaries: at the word boundary, at the phonological phrase boundary, at the intonational phrase boundary, and at the utterance boundary, the locations of which adhere to Nespor and Vogel's (1986) formulations. Also included in the sentence materials were those segments to which Linn (1988) reports voiced segments neutralize. These segments are /f,s,θ,p,t,k/.

In total, 6 segments that are predicted to exhibit devoicing, and 6 segments to which the devoiced segments might neutralize were distributed across words at each of the four prosodic boundaries, for a total of 48 arrangements of segments and prosodic positions. The segments at differing prosodic locations were embedded in 25 sentences.

The procedure for the experiment was as follows. Participants read the sentence materials three times (except M2 who read the sentences only twice), and the repetitions were recorded using Praat software running on a Dell Inspiron laptop computer. The recordings were saved as *.WAV files.

The experiment was conducted in the respective homes of the participants, except for speaker M2, where the experiment was conducted at a local restaurant before it opened to the public. After the experiment ended, recordings of target segments (along with preceding vowels) were extracted, saved, and labeled according to the segment, its prosodic location in the sentence, and the participant who uttered the segment.

Then, for each segment predicted to undergo devoicing, the author judged whether the segment indeed exhibited devoicing. The judgment was an impression based on listening to the segment and its preceding vowel. In cases where there was doubt about whether segments were devoiced, the segments were labeled as not having undergone devoicing. The point of making judgments about the quality of segments is to put segments into impressionistic categories so that comparisons can be made between (a) those segments that sound devoiced and those segments that do not appear to be affected by such processes, and (b) those segments that sound devoiced and those segments to which the affected segments supposedly neutralize.

4.3 Measurement and Analysis

Once judgments were made for each segment that had the potential to exhibit devoicing, the following acoustic measurements were taken of all segments: closure voicing duration of stops, voicing duration of fricatives, frication duration, oral closure duration of stops, and preceding vowel length (for both stops and fricatives). For voicing duration of fricatives, the measurement is from onset of aperiodic noise distributed over regular pulsation to the point in the waveform where periodicity was no longer present. Periodicity was determined by visual inspection of the waveform and spectrogram, as well as by use of the pulse-tracking algorithm in Praat. For frication duration, the measure is from onset to offset of aperiodic noise in the waveform. Closure duration of final stops is measured from the point where reduction in amplitude indicates that the articulators have closed the oral tract (Ladefoged 1982) to the point of release. For closure voicing of final stops, the measurement is from the point of oral closure to the point where voicing ceases. For vowel duration, the measurement is from the offset of the preceding consonant to the onset of the following consonant. Measurements of the segments were coded and analyzed in SPSS.

5 Results

Across all speakers, among the 485 segments that might have undergone devoicing, 66 stops and fricatives were judged by the author to have done so (about 14 percent of the dataset). There is no difference in the rate at which different speakers devoice fricatives, $\chi^2(3, N=146)=0.77$, $p=0.86$. However, devoicing rates for stops vary significantly among the speakers, $\chi^2(3, N=146)=9.42$, $p<0.05$. Speakers M2 and F2 exhibited fewer cases of stop devoicing compared to the other speakers (M1=15 cases of stop devoicing, F1=12, M2=8, F2 =4).

5.1 Neutralization

At issue with the segments judged "devoiced" is whether they inherit the acoustic characteristics of underlyingly voiceless fricatives and stops. Results indicate neutralization is not an operating factor with devoicing in IRE.

For fricatives, an analysis of variance was performed on voicing durations for each speaker, using as a factor group whether the fricative was underlyingly voiceless, judged "devoiced," or judged "voiced." Voicing durations among the segment types differ significantly for three of the speakers but not Speaker F2 (M1: $F(2,60)=26.17$, $p<0.01$, F1: $F(2,60)=20.70$, $p<0.01$, M2: $F(2,42)=7.85$, $p<0.01$, and F2: $F(2,53)=1.88$, $p=0.16$). Post-hoc analyses for the three speakers reveal that voicing duration of devoiced fricatives is no different from voiced fricatives but significantly different from underlyingly voiceless fricatives. That is, voiced and devoiced fricatives both exhibit longer voicing durations than underlyingly voiceless fricatives. Thus, the voicing contrast in fricatives is preserved, regardless of whether the fricative is judged as devoiced.

For stops, an analysis of variance was performed on closure voicing durations for each speaker, using as a factor whether the stop was underlyingly voiceless, judged "devoiced," or judged "voiced." All speakers exhibited differing voicing durations among the segment types, (M1: $F(2,71)=35.47$, $p<0.05$, F1: $F(2,72)=58.16$, $p<0.05$, M2: $F(2,48)=18.03$, $p<0.05$, and F2: $F(2,72)=12.21$, $p<0.05$). Post-hoc analyses reveal that speakers M1 and F1 significantly differentiate voicing duration between devoiced and underlyingly voiceless stops. These speakers also differentiate devoiced stops from voiced stops. Speakers M2 and F2 show no difference of voicing duration between devoiced and voiceless stops, but Speaker M2's devoiced stops exhibit significantly less voicing than his voiced stops. Thus, as with fricatives, "devoicing" of stops does not result in neutralization.

		Fricatives		Stops	
		VOI	FRI	VOI	CD
M1	Judged devoiced	35	154	28	70
	Judged voiced	38	114	53	69
	Underlyingly voiceless	10	143	4	84
	Total	23	133	23	77
F1	Judged devoiced	48	168	28	77
	Judged voiced	29	125	49	68
	Underlyingly voiceless	4	168	1	90
	Total	18	150	21	81
M2	Judged devoiced	24	128	21	80
	Judged voiced	13	95	44	58
	Underlyingly voiceless	1	109	4	81
	Total	9	108	20	73
F2	Judged devoiced	24	144	25	88
	Judged voiced	13	92	32	83
	Underlyingly voiceless	12	150	3	106
	Total	14	128	17	95
Total	Judged devoiced	32	146	26	76
	Judged voiced	25	108	43	71
	Underlyingly voiceless	7	146	3	92
	Total	17	132	20	82

Table 1: Means of acoustic durations of various stops and fricatives. VOI=voicing duration of fricatives or closure voicing, FRI=frication duration, and CD=closure duration.

5.2 Effect from Prosody

In addressing the distribution of devoiced segments at the various prosodic boundaries, results show that stops and fricatives judged as devoiced are unevenly present among the prosodic boundaries (for devoiced fricatives, χ^2 (3,146)=39.9, p<0.01, for stops, χ^2 (3,146)=41.6, p<0.01). In particular, the impression of devoicing was most likely to be identified for segments at the most prominent boundaries (See Table 2).

	Wrd	PholPhr	IP	Utt
Stops	0	3	15	21
Fricatives	0	0	9	18
Total	0	3	24	39

Table 2: Count of stop or fricative devoicing at each of four prosodic boundaries. Wrd=Word Boundary, PholPhr=Phonological Phrase Boundary, IP=Intonational Phrase Boundary, and Utt=Utterance Boundary.

Considering this distribution, ANOVAs were performed for each speaker on voicing duration and frication duration (for fricatives), closure voicing duration and closure duration (for stops), and preceding vowel length (for both stops and fricatives). For each speaker, the factors reported here are voiced/voiceless and prosodic position. Overall means for each speaker at each prosodic boundary are given in Table 3 below.

Regarding voicing duration of fricatives, three of the speakers exhibited no difference as a function of prosodic boundary (M1: $F(3,61)=1.3$, $p=0.29$, M2: $F(3,42)=0.19$, $p=0.90$, F2: $F(3,54)=1.33$, $p=0.33$). For the speaker where an effect is observed, (F1: $F(3,61)=7.52$, $p<0.05$), the duration of voicing is irregular and does not exhibit cumulative effects that might be expected. Results for voicing duration at each prosodic node is given in Figure 1 for underlyingly voiced fricatives.

Excepting speaker F1, no other speaker exhibits an interaction between the prosodic position of the fricative and the underlying voicing quality. Speaker F1's interaction between voicing and prosodic position is not due to obliteration of voicing contrast at certain prosodic boundaries. Rather, at the level of the phonological phrase and the utterance, the difference of voicing duration between underlyingly voiced and voiceless segments is much greater compared to the other prosodic boundaries. So, most of F1's irregular voicing durations are from the voicing duration of voiced fricatives at the phonological phrase and utterance boundaries, but the effect never blurs the distinction between voiced and voiceless fricatives. Thus, for all speakers, voicing contrast is maintained at each prosodic boundary, but overall, voicing duration is no longer at higher boundaries than it is at lower boundaries.

Regarding frication duration, all speakers exhibited differing durations depending on the fricative's location within an utterance, (M1: $F(3,61)=3.05$, $p<0.05$, F1: $F(3.61)=24.59$, $p<0.05$, M2: $F(3,43)=19.33$, $p<0.05$, and F2: $F(3,53)=46.2$, $p<0.05$). Post-hoc analyses reveal that frication duration is longer at successively higher prosodic nodes. For two of the speakers (F1 and F2), frication is longer for voiceless fricatives than for voiced fricatives.

Overall results for frication duration are given in Figure 2 for voiced fricatives. Note that in the figure, frication duration and voicing duration are graphed together. From this view, it is evident that the cumulative effect exhibited on frication duration is not evident in the voicing durations.

Interestingly, vowel length for three of the speakers (M1, F1, M2) is not contrastive before voiced and voiceless fricatives, (M1: $F(1,40)=3.50$, $p=0.07$, F1: $F(1,39)=0.80$, M2: $F(1,22)=0.26$, $p=0.67$, F2: $F(1,36)=10.08$, $p<0.05$). Thus, a crucial cue to the voicing quality of the following fricative is largely lost among the speakers.

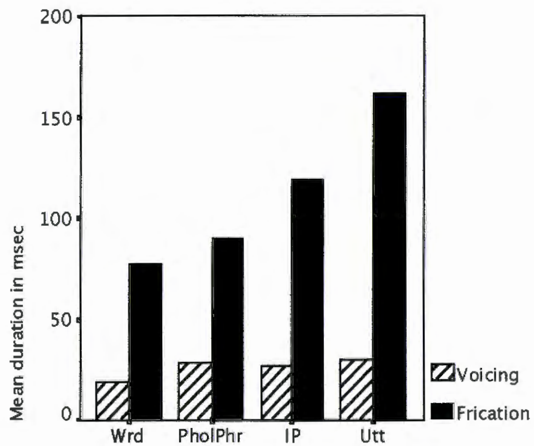

Figure 2: Voicing and frication duration of final *voiced* fricatives, by prosodic position, across all speakers.

In general, when results from prosody are compared to the results from fricatives judged to be devoiced, the clear correlate of devoicing is prosody's effect on frication duration at high prosodic boundaries that does not affect voicing duration. So, considering that cues from vowel length are absent, when the constriction gesture of fricatives reaches a decisive duration, the extra voiceless frication becomes a cue to devoicing, rendering unhelpful the voicing contrast preserved in the articulation of the consonant. In this way, Bauer's (2004) suggestion that devoicing in fricatives is a prosodic effect in IRE, not a result of neutralization, is supported here.

For stop characteristics, when comparing vowel length before voiced and voiceless stops, only two of the four speakers (F1, M2) exhibit longer vowel durations before voiced stops. The remaining two speakers do not exhibit differing durations before voiced and voiceless stops, (M1:

F(1,46)=0.25, p=0.62, F1: F(1,47)=15.80, p<0.05, M2: F(1,22)=2.24, p<0.05, F2: F(1,45)=2.24, p=0.14). The results, while not as clear as with fricatives, suggests that vowel duration is not a reliable cue to voicing of stops in IRE.

		Stops			Fricatives		
	Boundary	V DUR	VOI	CD	V DUR	VOI	FRI
M1	Wrd	149	35	69	164	19	96
	PholPhr	166	19	72	205	19	137
	IP	203	26	82	237	27	147
	Utt	182	13	81	207	26	141
	Total	175	23	77	207	23	133
F1	Wrd	171	32	71	201	10	96
	PholPhr	203	25	67	237	24	117
	IP	241	20	79	279	11	129
	Utt	216	8	103	247	25	232
	Total	209	21	81	244	18	150
M2	Wrd	147	25	48	154	8	74
	PholPhr	159	29	67	187	11	74
	IP	181	15	85	229	8	125
	Utt	164	10	88	210	10	138
	Total	163	20	73	199	9	108
F2	Wrd	123	30	79	133	12	81
	PholPhr	128	22	85	138	14	85
	IP	176	13	103	207	15	126
	Utt	178	3	109	206	14	192
	Total	152	17	95	175	14	128
Total	Wrd	147	31	68	164	13	88
	PholPhr	165	24	74	193	17	105
	IP	204	19	87	240	16	133
	Utt	187	9	96	218	20	178
	Total	176	20	82	208	17	132

Table 3: Mean acoustic durations of various characteristics related to fricatives and stops. Wrd=Word Bounary, PholPhr=Phonological Phrase Boundary, IP=Intonational Phrase Boundar, Utt=Utterance Boundary, V DUR=Vowel Duration, VOI=Voicing duration (closure voicing and voicing of fricative), and FRI=Frication duration.

Closure voicing duration in stops did not pattern like voicing duration in fricatives. Rather, while there is an overall effect of prosody on voicing duration in stops, duration is shorter at higher prosodic nodes, shown in Figure 3 for voiced stops. Three speakers exhibit an effect from prosody (M2 did not), (M1: F(3,72)=3.02, p<0.05, F1: F(3,73)=8.31, p<0.05, M2:

F(3,49)=2.40, $p=0.09$, and F2: F(3,72)=6.16, $p<0.05$). Post-hoc analyses indicate that closure voicing duration of stops is significantly shorter between the lowest and highest prosodic boundaries, but durations at adjacent boundaries are not significantly different.

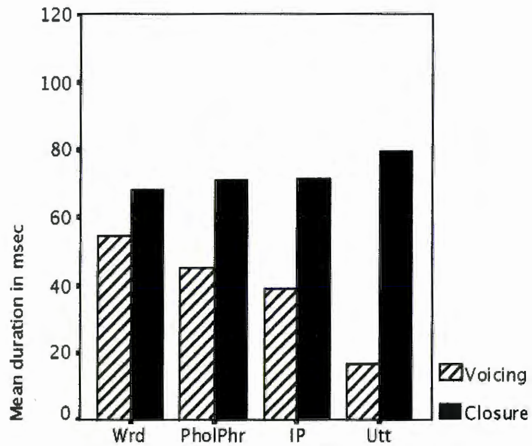

Figure 3: Voicing duration contrast between underlyingly *voiced* stops, by prosodic position, across all speakers.

Among the three speakers that exhibit an effect from prosody on voicing duration, there is no interaction between the position of the stop within an utterance and underlying voicing quality. Thus, for each speaker (including the fourth speaker who shows no effect from prosody), the contrast between voiced and voiceless stops is maintained at each prosodic boundary.

Three of the speakers exhibit an effect from prosody on the duration of oral closure of final stops; M1 does not show an effect (M1: F(3,68)=1.30, $p=0.28$, F1: F(3,69)=13.2, $p<0.05$, M2: (3,44)=8.56, $p<0.05$, F2: F(3,64)=12.79, $p<0.05$). Post-hoc analyses of the three speakers indicate that closure duration of stops at the highest prosodic positions is longer than at the lowest positions, but durations between adjacent boundaries are not significantly different for Speaker M2. Overall results for voiced stops are shown in Figure 3.

Overall, closure duration in stops is longer at higher prosodic boundaries but closure voicing duration is shorter. The shortening of voicing at higher prosodic boundaries is surprising, considering that effects from prosody usually result in a cumulative lengthening effect, not an overall shortening one. Obviously, since the articulators create a complete closure in the vocal tract, vocal fold vibration will cease because adequate subglottal air pressure cannot be maintained. Possibly, the longer closure duration contributes to an overall shortening of voicing duration: several authors have noted that longer durations at higher prosodic boundaries are correlated with greater articulatory contact (Keating and Fougeron 1997, Cho 2001, Tabain 2003a,b, Keating, Wright, and Zhang 2003). So, greater contact may more quickly neutralize air pressure below the vocal folds, making impossible an environment for vocal fold vibration to persist. Thus, as contact increases, voicing duration becomes shorter regardless of intended duration. This effect is not noticed with fricatives, because, since the vocal tract is never completely obstructed, adequate pressure differential to achieve voicing can be maintained. The limitation with this interpretation is that closure duration for the voiced stops does not increase at the same rate as closure voicing decreases, so it appears that an active gesture is made to terminate closure voicing earlier on in the closure at higher prosodic boundaries. Thus, it seems the effect of prosody on stops is to lengthen the constriction gestures while actively making stops less sonorous and still preserving voicing contrasts. It is quite likely that the greater difference in closure voicing and overall closure duration at higher prosodic boundaries in IRE give a cue that the stops are voiceless, especially considering that vowel duration is not a reliable cue. In this way, results for stops pattern like fricatives in that devoicing results from a prosodic effect, not a neutralizing one.

6 Conclusion

The present study makes two significant points. Locally, results from the experiment explain why segments in Iron Range English sometimes give the impression of being devoiced. Devoicing in IRE is caused by an effect from prosody on underlyingly voiced final stops and fricatives. Results for underlyingly voiced stops and fricatives shows that frication duration of fricatives is successively longer at positions of greater prosodic prominence, whereas voicing duration remains unchanged. In addition, closure duration in stops is slightly (but significantly) longer at more prominent positions and voicing duration is shorter. Taken together, the overall effect of prosody on underlyingly voiced stops and fricatives in IRE makes the segments less sonorous and more constricted. The effect is strong enough that the extra frication and larger differential between durations of stop closure and vocal fold vibration are cues to voicelessness that occasionally give the impression of devoicing. Crucially, effects from prosody are exhibited in all domain-final stops and fricatives in IRE, not just ones judged to be devoiced. Along these lines, Bauer (2005) reports that the effect from prosody also gives rise to nasal hardening in IRE ("sink" for "sing"), so the effect of prosody is a *gen-*

eral process present in the dialect affecting all segments at prominent boundaries of prosody.

Results add to recent work demonstrating effects from prosody vary across languages (Kuzla and Cho 2004 for fricatives in German, Tabain and Perrier 2005 for /i/ in French, Cho and McQueen 2005 for /t/ in Dutch, and Cho 2005 for /i/ in English).

Broadly, prosodically-conditioned devoicing in IRE highlights the need for close analysis in addressing phonetic variation. Measurement of the dependent variable within quantitative sociolinguistics usually consists of identifying whether a segmental feature is present or absent in speech, e.g., t/d deletion in African American Vernacular English ("work" for "worked"), r-dropping in Boston English ("cah" for "car"), l-insertion in Western Pennsylvania English ("howl is" for "how is"), and monophthongization ("ah" for "I") in South Atlantic Speech (Chambers 1995:17; Milroy and Gordon 2003:4; Wolfram and Schilling-Estes 1998). While the measure has proven incredibly useful, variation that leads to the impression of sound change sometimes requires fine-grained acoustic or articulatory analysis in order to uncover underlying loci of control. In the case of Iron Range English, dialect-specific suprasegmental variation gives rise to segmental effects that impression alone cannot capture.

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