Acoustic Correlates of Lenis and Fortis Stops in Manitoba Saulteaux

by

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Abstract

This study investigated some of the acoustic correlates of lenis-fortis contrast in Saulteaux Ojibwe based on speech from six speakers in Manitoba. Four acoustic correlates of lenis and fortis stops in intervocalic position were measured; consonant duration, postaspiration, preaspiration and sonority level. It was assumed that although the speakers displayed much variation in terms of what correlates marked the contrast overall the contrast would be maintained with a similar degree of robustness across the speakers. It was hypothesized that despite the ubiquitous variation, the speakers would trade off acoustic correlates in order to maintain the contrast. Bias-reduced multiple logistic regression models were used in order to assess the (non)importance of each correlate by speaker. Multi-model inference was used in order to choose the best model for each speaker based on their speech. Some trading relations between the correlates were discovered across the speakers, however, the precise quantitative weightings between them were difficult to assess for a number of reasons. The relevance of the current study for Ojibwe dialectology is discussed.

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1. Introduction

This thesis describes some of the acoustic correlates of the lenis-fortis contrast in Saulteaux. Saulteaux is a dialect of Ojibwe spoken from western Ontario through Manitoba and Saskatchewan to Alberta (Rhodes & Todd 1981, Valentine 1994). Historically the speakers of this dialect are thought to have migrated from the Great Lakes area (Bishop 1974, 2002, Peers 1994). What is termed "Saulteaux" in the linguistic literature overlaps with what are considered two distinct cultural groups in the anthropological literature (Steinberg 1981, Albers 2001).

Ojibwe is an Algonquian language which extends from eastern Quebec to Alberta and southward into Michigan (Rhodes & Todd 1981). It has often been designated as a central Algonquian language (along with Cree, Menominee and Fox (e.g. Bloomfield 1925)), however, the general consensus in Algonquian linguistics is that the central languages do not constitute a genetic subgroup (e.g. Pentland 1979, Goddard 1981).

Despite the fact that this thesis compares the acoustic correlates of the lenis-fortis contrast in what might be termed "subdialects" of Saulteaux, since the speakers are from different communities, I make no claims about dialect classification in Ojibwe. The scope is purely descriptive, statements about "phonetic distance" are not meant to imply anything with regards to dialect categories, isoglosses and the like. A brief and cursory discussion of the relevance of the current study for Ojibwe dialectology will be given in the final discussion.

Two main intellectual pursuits have motivated this study. The first is the empirical findings and concomitant methodological reorientation of Laboratory Phonology that attempts to articulate the relationship between phonology and phonetics (cf. Pierrehumbert, Beckman & Ladd 2000). Close attention to phonetic detail and micro-variation is an important methodological value in this paradigm (e.g. Docherty 1992). The other field of study which has motivated the writing of this thesis is Ojibwe dialectology (cf. Valentine 1994, 1996). This thesis attempts to catalogue and describe in greater depth a parameter of phonological variation in Ojibwe for the Saulteaux dialect. Ojibwe dialects are thought to vary according to the subphonemic content of the lenis-fortis classes (Valentine 1994). Laboratory Phonology and Ojibwe Dialectology converge towards the same goal when one attempts to describe the phonetic content of the natural classes, lenis and fortis obstruents, in Ojibwe, the topic of this thesis.

This thesis is structured as follows. In chapter 2, I review the phonological and impressionistic phonetic literature of the lenis-fortis contrast in Ojibwe. Attention will be given to the evolution of the contrast with reference to the literature on Algonquian historical phonology. Some of the morphophonemic phenomena that relate specifically to the lenis-fortis contrast will be reviewed. This chapter is meant only to summarize the descriptive facts reported to date as they pertain to phonotactic distributions and phonological alternations in Ojibwe. Although The latter can inform what one looks for in the phonetics. The primary concern of this thesis is with the phonetic content of the natural classes lenis and fortis. Chapter 3 describes the basic outlines of the theory of phonology and phonetic used in this thesis. The specific hypothesis investigated in this thesis is whether the robustness (or phonetic distance) between lenis and fortis stops is approximately the same when the relevant factors are considered in tandem, despite each stop differing from one another quite strikingly in terms of the phonetic coding along each parameter taken individually. I suggest that using loglinear regressions is a useful tool for investigating this hypothesis. I propose various ways of corroborating the hypothesis, all of which nonetheless have some problems associated with them. Chapter 4 contains the main content of this thesis. Here I describe the methodology used in the instrumental studies. I then compare the lenis-fortis contrast in speakers separated by place of articulation (henceforth POA). This is in part an arbitrary decision. I could have equally well described each speaker and had POAs as subsections for each speaker. The reason I chose this format was so that speakers could be compared throughout the discussion. This will help us in considering the hypothesis investigated in this thesis.

The final chapter summarizes the results; contextualizes them with respect to the phonetic realization of lenis-fortis consonants cross-linguistically, i.e. for phonological typology (Lindblom & Maddieson 1986) and gives a brief discussion of the relevance of the present study for Ojibwe dialectology. Finally I emphasize the limitations in scope of the present study and highlight the need for future research.

2. Phonological Grammar

This section gives phonological context to the acoustic investigation undertaken in chapters 5 and 6. I assess the phonological evidence that fortis consonants are underlying consonant clusters. Despite this, at a surface level lenis and fortis consonants have been described as falling into distinct natural classes. Three types of phenomena are generally thought to require the use of natural classes/distinctive features in order to account for them (Hall 2001:

4). The first is the need to account for natural classes in the phonological inventory of the language. The second is the particular phonological processes or distributional constraints that need to make reference to one of these classes. The third is the need to capture natural classes cross-linguistically. This chapter is focused on describing the lenis/fortis consonants with reference to the first two of the aforementioned phenomena described above. The historical development of the contrast, and the morphophonemic rules that might make reference to it, provide us with clues to what phonetic attributes might encode the lenis-fortis contrast irrespective of the theoretical framework adopted (cf. Pierrehumbert 2001b).

A number of different orthographies are used for Ojibwe. For the section on phonology, we use the orthography from Bloomfield (1956) and Nichols (1980) since it is better able to capture the relationship between Ojibwe and other Algonquian languages (e.g. Bloomfield 1946, Pentland 1979). The lenis and fortis obstruents of Ojibwe are written as follows.

(1) The lenis and fortis consonant in Ojibwe (Bloomfield 1956, Nichols 1980, et al.)

lenis	fortis
p	pp
t	tt
k	kk
s	ss
š	šš
c/č	cc/čč

The notation that represents fortis consonants as geminates or double lenis consonants reflects their historical development from consonant clusters (cf. 2.1.). <š> represents a postalveolar fricative [ʃ], and <c> represents a postalveolar affricate [tʃ]. In the section on phonetics I switch to a different orthography from Nichols & Nyholm (1991) for reasons discussed below.[1] We now review the historical development of the lenis-fortis contrast in Ojibwe and its relationships to its synchronic phonology.

2.1. Evolution

This section describes the diachronic development of lenis and fortis consonants in Ojibwe with reference to some of the explanatory principles of Evolutionary Phonology (cf. Blevins 2004), specifically how this theory explains geminate inventories. The first premise of Evolutionary Phonology is that in order to understand the phonology of a language it needs to be contextualized with respect to its historical development. As we will see, this approach also motivates the phonetic correlates investigated in this study. The reason for this is that, apart from serving as the basis for phonological change itself, the phonetic content of phonological contrasts often has a partly evolutionary basis (cf. Labov 1994, Blevins 2004, Bermúdez-Otero 2007).

In Blevins' approach to phonology, the phonetic basis of sound change is considered one of the main driving forces behind the development of phonological structure. The phonetic encoding of phonological systems is systemic enough to maintain contrast between their combinatorial primes (phonemes, gestures, syllables etc…) for a generation of speakers, and yet flexible due to the inherent phonetic variability that arises from the tug-of-war between perceptual and articulatory drives (Lindblom 1990, Boersma 1998). The variability encodes the potential for

[1] It has often been noted that in some dialects of Saulteaux the s~ss and š~šš distinction is being lost due to contact with Plains Cree, which lost this distinction (Valentine 1994, Goddard 2001). This is a serious research question that deserves instrumental investigation, though it is not addressed in the current study because the acoustic analysis is limited to stops.

phonological change. While recurrent sound patterns could be due to a number of factors[2], Evolutionary Phonology attempts to account for these as much as possible with reference to "parallel evolution in the form of parallel phonetically motivated sound change" (Blevins 2006: 120) rather than assuming that these are prima facie attributable to innate aspects of phonological structure, requiring hypothetico-deductive models.[3]

Blevins (2004, 2005) has recently discussed the typology of geminates in terms of their various patterns of convergence. She identifies seven different pathways of development given in (2).

(2) General pathways in the evolution of consonant length contrasts (Blevins 2004: 170)

(a) assimilation in consonant clusters

(b) assimilation between consonant and adjacent vowel/glides

(c) vowel syncope

(d) lengthening under stress (including expressive lengthening)

(e) boundary lengthening

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[2] According to Blevins (2006: 120) these are; "(i) inheritance from a mother tongue; (ii) parallel evolution in the form of parallel evolution in the form of parallel motivated sound change; (iii) physical constraints on form & function, in particular, innate aspects of speech perception & production, and potential phonological universals; (iv) 'non-natural' or external factors (e.g. language contact, prescriptive norms, literacy, second-language learning); (v) or mere chance."

[3] This is not to say that generative models did not understand that many of the rules they posited had a phonetic basis in sound change (cf. Belvins 2006 for details). The statement above should be regarded as indicative of a methodological shift, with consequences for how we explain the relevant empirical phenomena, i.e. what theories we posit (cf. Lauden 1977). Blevins describes this reorientation succinctly:

> "The premise is that principled extra-phonological explanations for sound patterns have priority over competing phonological explanations unless independent evidence demonstrates that a purely phonological account is warranted… this means that similar sound patters which are directly inherited from a mother tongue (a), the consequence of recurrent natural phonetically motivated sound change (b), the result of language contact, prescriptive norms or literacy (d), or due to chance (e), should not be attributed to innate linguistic phonological knowledge (c)." (Blevins 2006: 124)

See Lindblom et al. 1984 for an earlier formulation of this methodological standpoint.

(f) reinterpretation of a voicing contrast

(g) reanalysis of identical C+C sequences

Certain facts about phonological inventories can be understood with reference to the historical origin of these contrasts. For instance (a) will tend to create relatively smaller inventories of geminates compared to (c). The reason for this is that consonant inventories derived from (a) will only have geminates from assimilating clusters. There may have been distributional constraints that prevented such consonant clusters in the lexicon. Geminates developed from (c) are more likely to produce all of the combinations, i.e. have a geminate for every singleton. For example, Palaun and Wichita have two and three geminates from syncope between identical consonants and have a nearly full geminate inventory (Blevins 2008).

Distributional facts are predictable from the pathways stated in (2) as well. Many languages have constraints whereby geminates cannot occur word-initially. When we think about allophony in relation to word position, this has a rather obvious phonetic explanation. It is often impossible to parse the length of a plosive that appears word-initially because there is no way to discern the onset of the closure (Blevins 2004): 181-3). In terms of the distribution of phonemic contrasts, the distribution of geminates in a language will be predictable from the distribution of consonant clusters in the protolanguage. For instance geminates in Nhanda are restricted to intervocalic position. In Proto-Pama Nyungan and Pre-Nhanda consonant clusters were restricted to word-medial position (Blevins 2001).

Fortis consonants in Ojibwe have roots in pathway (2a), assimilation of consonant clusters.[4] Ojibwe is perhaps a typological outlier compared to the 73 languages surveyed by Blevins (2010), since the consonants in (1) represent 12 out of the 16 consonant in the entire inventory and thus have close to a "full" geminate inventory in Blevins' sense, despite having their evolutionary origins in (a). As noted repeatedly in the literature (e.g. Piggott 1980, Valentine 1994, et al.), fortis consonants in Ojibwe do not occur word initially because of a constraint in Proto-Algonquian that disallowed consonant clusters in this position.[5] Bloomfield (1925, 1946) reconstructed the Proto-Algonquian phonological inventory using primarily Ojibwe, Cree, Menominee and Fox (but cf. n5).

Cognate by cognate comparisons demonstrate that fortis consonants in Ojibwe are comparable with consonant clusters in other central Algonquian languages. An example of this is given in (3). Here the Ojibwe geminate consonant /pp/ reconstructs to Proto-Algonquian */čp/ based on its correspondences with other Algonquian languages.

(3) PA *noo***čp***inatamwa "he pursues it": Cree noo**sp**inatam, Ojibwe noo**pp**inatank: Menominee noo***čp***enεεhtaw. (Bloomfield 1946: 88)

[4] A rich literature on the historical phonology of Algonquian languages has developed since the pioneering work of Bloomfield (e.g. Bloomfield 1925, 1946, Goddard 1979, 1990, Michelson 1935, Pentland 1979, Siebert 1941, et al.). The reconstruction is essentially undisputed except for minor adjustments.

[5] It should be noted, however, that certain Ojibwe dialects may be creating additional geminates through vowel syncope. Eastern dialects of Ojibwe undergo various syncopation processes (Piggott 1980, Valentine 2001). Syncopation occurs in other Ojibwe dialects as well but to a lesser degree than in Odawa (Valentine 1994). Vowel syncopation in fast speech does occur in Saulteaux but I have not observed that its presence is so ubiquitous to conclude that this dialect is undergoing geminate formation from vowel syncope. I have one example from a speaker from Sandy Bay (KL), taken from conversation where two homorganic lenis consonants concatenate through syncopation to produce what seems to be a fortis consonant in terms of being voiceless, with a long aspiration. This does not, however, appear to be a particularly common phenomenon.

Every geminate in Ojibwe is historically related to a Proto-Algonquian consonant cluster as is demonstrated in (4).

(4) The reconstruction of PA clusters from geminates in Ojibwe

(Bloomfield 1946: 88-90)

PA	Ojibwe	Cree	Menomi	Fox
*hp	pp	hp	hp	?
*xp	pp	sp	hp	hp
*čp	pp	sp	čp	?
*ht	tt	ht	ht	ht
*qt	tt	st	qt	ht
*hk	kk	hk	hk	hk
*xk	kk	sk	hk	hk
*θk	kk	sk	hk	hk
*hč	čč	hč	hč	hč
*qč	čč	sč	č	hč
*hs	ss	s	hs	s
*qs	ss	s	qs	s
*hš	šš	s	hs	š
*qš	šš	s	qs	š
*hθ	ss	ht	hn	s
*qθ	ss	st	qn	s
*hl	ss	hy	hn	s
*ql	ss	hy	qn	s

Most cases of fortis consonants in Ojibwe seem to be the result of regressive place assimilation from non-homorganic Proto-Algonquian consonant clusters. The direction of assimilation in geminates has some fairly straight forward phonetic motivation (cf. Blevins 2004: Ch.5).

Rhodes (2006) posited that in "Proto-Ojibwe" (or Old Ojibwe) fortis consonants went through an intermediate hC stage (e.g. xk → hk → kk, qt → ht → tt). This is presumably based on the fact that in some dialects of Ojibwe fortis consonants are described as preaspirated (e.g. Valentine 1994), and thus the most economic explanation of the current state of affairs is that the northern dialects reflect the more conservative variant (more on this later). In Blevins' typology of sound changes[6] (Blevins 2004, 2006) the first stage ($C_1C_2 \rightarrow hC_2$ where subscripts indicate POA identity) is an instance of what is termed CHANGE whereby "The phonetic signal is misperceived by the listener due to: acoustic similarities between the utterance and the perceived utterance; and biases of human perceptual system" (Blevins 2006: 126). Experimental results consistently show that CV transitions provide more prominent place cues than VC transitions (e.g. Repp 1978, Fujimora et al. 1978, Ohala 1990). Thus, the preconsonantal C_1 in the cluster C_1C_2 is perceptually weaker with regards to its place features.[7] This explains why C_1C_2 clusters in (4) all underwent regressive and not progressive place assimilation.

The second stage of the development ($hC_2 \rightarrow C_2C_2$) would have been an instance of CHOICE in Blevins' (2004, 2006) model; "Multiple phonetic variants of a single phonological form are accurately perceived by the listener. The listener (a) acquires a proto-type or best exemplar which differs from that of the speaker; and/or (b) associates a phonological form in the speaker's

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[6] The typology consists of three types of sound change, two of which are described above. The other is "CHANCE: The phonetic signal is accurately perceived by the listener but is intrinsically phonologically ambiguous. The listener associates a phonological form with the utterance which differs from the phonological form in the speaker's grammar." (Blevins 2006: 126).

[7] Actually according to this account it is unlikely that all consonant clusters took this path. Only those with preconsonantal fricatives would have an intermediate stage of hC clusters. The preaspiration in clusters derived from stop-stop combinations in Proto-Algonquian probably received preaspiration (as a segment or correlate) through structural analogy (roughly in Blevins 2006: 128 sense). The PA fricative-stop clusters PA thus went through the process $C_1C_2 \rightarrow hC_2 \rightarrow C_2C_2$ where identical subscripts equal identical POAs. The PA stop-stop clusters most likely went through $C_1C_2 \rightarrow C_2C_2$. In the case of northern dialects the first set may have analogized to the second in its second stage thus making all segments hC_2.

grammar." (Blevins 2006: 126). In some speech registers (e.g. hypospeech (cf. Lindblom 1992)) the preconsonantal glottal friction associated with preaspiration, i.e. the /h/ segment, would likely drop out. This percept could easily be transformed into the articulatory domain through laryngeal retiming. In some dialects (e.g. "southern"), the onset of the voiceless laryngeal gesture, previously realized as glottal frication preceding the stop, would align its onset with the onset of the supralaryngeal place feature associated with C_2 (cf. Blevins 2004: Ch.5). As we will see, this crude account is an oversimplification since preaspiration in Saulteaux is variable, implying that there is no discrete transition from hC_2 to C_2C_2 clusters.[8, 9]

In addition to the distributional facts passed on from Proto-Algonquian, the apparent phonetic basis underlying the development of the lenis-fortis contrast will motivate our phonetic studies. We will discuss the relevance of the diachronic development of the lenis-fortis contrast for the the phonetic encoding of the lenis-fortis contrast in 2.4.

2.2. Morphophonological Correspondences

In this section I review the synchronic phonological data that have led researchers to suggest that fortis consonants are underlying consonant clusters, possibly lenis-lenis (e.g. Piggott 1980). Most of the empirical facts reviewed here are discussed in Piggott (1980) and the papers

[8] It is not clear what the phonetic grounds are for distinguishing between /hk/ and /^{h}kk/ in the apparent diachronic process /hk/ → /^{h}kk/ where the h superscript represents glottal frication before the closure. The difference (perhaps) hinges on whether in /hk/ sequences the /h/ is obligatory whereas in /^{h}kk/ the preaspiration correlate is only optional, contingent on the weighting of other factors in the signal. Instrumental phonetic studies on the synchronic state of preaspiration (e.g. Helgason 2002) suggest that the process is gradual. There cannot be any simple threshhold whereby a /hk/ becomes /^{h}kk/.

[9] Furthermore, where it has been investigated preaspiration seems to persist as breathy voice (H1-H2) in the preceding vowel (e.g. Blankenship 1997, Gobl & Ní Chasaide 1999). Thus in addition to the variable realization of preaspiration there is never a discrete point at which we can say that modal voicing has stopped and glottal frication has begun, rather they overlap (cf. also Hoole, Gobl & Ní Chasaide 1999).

from the Odawa Language Project (Kaye et al. 1971, Piggott & Kaye 1973) described in an SPE framework (Chomsky & Halle 1968). Piggott's primary concern was with the necessity for abstract representation and rule-ordering, not with phonetic interpretation. Only the evidence as it pertains to the phonological nature of fortis consonants is presented here, however. Phonetic motivation for the phonological processes based on Jun's (2004) account of consonant assimilation is given. Despite the fact that almost all of these data are also presented in Piggott (1980), I use data from my own field data from Saulteaux.

The phonological alternations that give evidence for the lenis-fortis distinction in Ojibwe can be separated according to the level of morphological derivation they make reference to; either inflectional or derivational boundaries. The inflectional processes are cases of regressive assimilation that occur at a morpheme boundary. A fortis consonant derives from two underlying lenis consonants. One occurs with the AI and TA[10] verb paradigms with the third person conjunct marker lenis coronal stop -t (5a). When the preterit suffix -pan (5b) is concatenated this produces a fortis /pp/ (5c) (Piggott 1980: 133).

(5) t+p → pp
(a) *mii appii kaa=maačaa***t**
mii appii kaa=maačaa-**t**
EMPH when C-leave.AI-3.C
'That's when he left.'
(b) nii=waapamaa**p**an
ni-wii=waapam-aa-**p**any
1-DES=see.TA-DIR-PRET
'I was going to see him...
(c) mii appii waa=wiintamawaa**pp**an
mii appii waa=wiintamaw-aa-**t-p**any

[10] AI refers to an intransitive verb which takes an animate subject. TA refers to a transitive verb with an animate object (cf. Bloomfield 1962 for the relevant terminology).

EMPH when DES.C=tell.TA-DIR-3.C-PRET
'That's when he was going to tell him.'

The other strengthening process occurs when a stem final lenis /t/ (6a) precedes the inanimate intransitive (II) verb singular conjunct marker -k (6b) at a morpheme boundary. Regressive assimilation produces a word final /k/ (6c) (cf. Piggott 1980: 135).

(6) t+k > kk
(a) sanaka**t**
be.difficult.II
'It's difficult.'
(b) nkikkentaan miskwaa**k**
n-kikkent-aa-n miskwaa-**k**
1-know.TI-DIR-0 be.big.II-0.C
'I know it's big.'
(c) nkikkentaan sanaka**kk**
n-kikkent-aa-n sanaka**t-k**
1-know.TI-DIR-0 be.difficult.II-0.C
'I know it's difficult.'

Thus, both cases of strengthening involve the lenis coronal stop /t/. Another phonological alternation occurs when the derivational suffix -toon is added to a TA verb to derive a TI verb. A TA verb ending in /h/ or /ʔ/ (7a), depending on the dialect (Valentine 1994: 122), with the TI forming -toon (7b) creates a /tt/ (7c) at a morpheme boundary. We represent the derivational stem boundary with + in the parse (cf. Piggott 1980: 132).

(7) *h/ʔ+t >tt*
(a) *nkii=nači***ʔ**aa
n-*kii=nači***ʔ**-aa
1-PAST-abandon.TA-DIR
'I abandon him.'
(b) nkii=pii**t**oon
n-kii=pii+**t**oon
1-PAST-bring+TI

‘I brought it.’
(c) *nkii=nači***tt**oon
n-*kii=nači***ʔ+t**oon
1-PAST=abandon+TI
‘I lost it.’

There are two ways of describing the processes above. We can describe them as cases of strengthening as in Nichols (1980: 268): "A non-nasal dental obstruent (/t/, /N/) tenses a following obstruent and is itself deleted". Or we can view them as cases of regressive assimilation, based on underlying consonant clusters (Piggott 1973, 1980). There are other cases where stem final nasals assimilate to the following consonant. These are irregularities based on historical mergers, usually accounted for with the use of morphophonemes (as in Nichols (1980) /N/ above, Bloomfield 1956, Kaye 1971, Piggott 1980). However, it is possible to analyze the 2>3 conjunct marker (8c) as underlyingly the thematic second person patient marker (or local "inverse" in some descriptions) -in (8) combined with a third person conjunct marker -k (8a).

(8) n+k > kk
(a) *mii appii kaa=takoši***nk**
mii *appii kaa=takoši***n-k**
EMPH when C=arrive.AI-3
‘That’s when he arrived.’
(b) kikii=waapami**n**
ki-kii=waapam-i**n**
2-PAST-see.TA-INV/2.P
‘I saw you.’
(c) appane kaa=waapami**kk**
appane kaa=waapam-i**N-k**
when C-see.TA-INV/2.P-3
‘When did he see you?’

Bloomfield (1946: 102) reconstructs the second person theme sign of Proto-Algonquian as -*eθ*. The PA equivalent of the 2>3 -ikk suffix in Ojibwe is accordingly -*eθk*. In Ojibwe short */i/ and short */e/ merged to /i/. There is synchronic evidence of this in certain asymmetrical patterns of palatalization, not taken up here (cf. Piggott 1980, Nichols 1980, et al.). Recall from (4) that PA /*θk/ changed to fortis /k/ in Ojibwe. PA /*θ/ and /*n/ merged to /n/ in Ojibwe. This explains the morphophonemic asymmetries in (8).[11] Synchronically these phenomena have been accounted for with morphophonemes that undergo absolute neutralization in the phonetic component. (Piggott (1980: 173) for example chooses to regard /n/s that undergo this process as underlying /l/s, which never surface phonetically).

There is one case where a fortis consonant turns into a lenis consonant. When the negative suffix –ssii (9) is concatenated with a nasal at a morpheme boundary it is transformed to –sii [zi:] (10). Thus, the voicing feature assimilates to the fortis consonant from the previous nasal. In Saulteaux it appears that the nasal stop is deleted completely.

(10) n+ss> ns [nz]
(a) gaawn nkii=kanoonaassii
gaawn n-kii=kanoon-aa-ssii
NEG 1-PAST-speak.TA-DIR-NEG
'I didn't speak to him.'

(b) gaawn nkii=noontaasii
gaawn n-kii=noont-aa-n-ssii
NEG 1-PAST-hear.TA-DIR-0-NEG
'I didn't hear it.'

[11] In Berens and Northern Ojibwe, the stems of II verbs ending in /t/ have been reanalyzed as ending in /n/. Thus, the same morphophonemic alternation would occur in my example in (6) as well.

Regressive coronal place assimilation as in the examples in (5-6) is common cross-linguistically (Jun 2004). In a general sense it mirrors the evolutionary process that created geminates to begin with.[12]

Coronal assimilation is typologically well-attested. There is a phonetic basis for this in the inertial motor properties of coronals as they relate to their place cues as opposed to other obstruents (Jun 2004). Recall that there are stronger place cues after the release of a consonant than before it (Fujimura et al. 1978). There are no place cues for oral stops during the closure and only weak place cues for the nasal stop (Repp & Svastikula 1988). The typological asymmetry of greater coronal assimilation for stops is based on differences in articulatory timing and how this relates to the place cues present in the surrounding vowels. Bilabials and velars have more sluggish articulations compared to coronals. The former have more salient place cues because they have a substantial effect through a longer portion of the vowel. The difference can be represented in (12b) where C_1 is a coronal and C_2 is a bilabial or a velar. The C_2 gesture even has observable effects on the prevocalic place cues of C_1 thus further obscuring the perceptual cues to /t/ in consonant clusters (cf. Dilley & Pitt 2007). (12a) represents a case where both of the gestures have similar trajectories before and after their targets.

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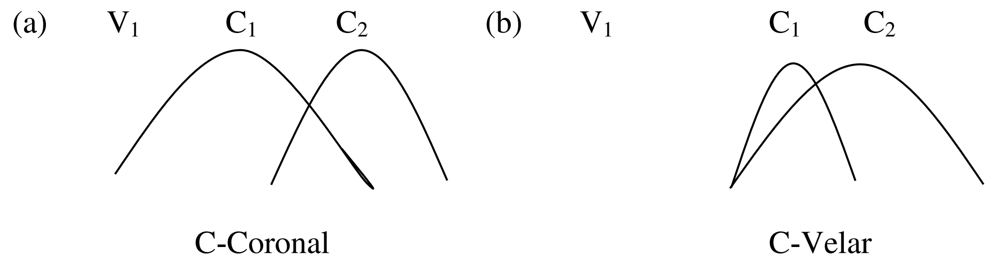
[12] Another consonant mutation occurs at the boundary between stem and –toon; *nittoon* 'kill it' from niss 'kill him'. I am uncertain as to the origins of this word, but it is the only case where the consonant mutation is not necessarily analyzable as underlyingly two lenis consonants, the example in (b) is from pedagogical material produced by Black River First Nation.

ss+t> tt
(a) okii=nissaan
o-kii=niss-aa-n
3.ERG=kill.TA-DIR-0
'He killed him.'
(b) *aaniin ke=iši=antawenčikeyaan, kekoo či-***nittoo***waan kemaa ke=iši=pimaači?owaan?*
aaniin ke=iši=antawenčike-yaan,kekoo *či*-**niss-too**-*waan kemaa ke=iši=pimaači?*-owaan
how FUT.C=thus=hunt.AI-1.C thing C-kill.TA+TI-1.C pc FUT.C=thus=provide.AI-1.C
'Then how can I hunt, kill my game, or make my living.' (Black River First Nation 2005)

(12) Assymetry in place cues for consonant clusters (from Jun 2004: 64)



According to Jun (2004) the weaker perceptual correlates of preconsonantal obstruents account for the fact that coronals are more liable to assimilate regressively in consonant clusters. The historical development of the alternation in (7) would have occurred through retiming the homorganic glottal gesture with one larger dorsal or bilabial gesture. It is important to note that despite the fact that the rule in (11) and its explanation in (12) are correct for the phonological alternations observed above, they are not obviously general phonological processes. In fact they appear to be very morphologically specific. In the absence of rampant vowel syncope as in Odawa (e.g. Valentine 2001), the process in (5) for instance is morphologically restricted to cases where there is a clearly analyzable third person conjunct -t, all other clusters being split up by epenthesis (13).[13] These data are from my own field research.

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[13] Another process that prevents concatenation of stops involves the vocalization of an underlying glide dropped in hiatus position by an extremely productive rule in Ojibwe.

Vocalization of underlying w.

(a) kikii=waapamik
ki-kii=waapam-ikw
2-DES.C-see.TA-INV
'He saw you.'
(b) kikii=waapamikopan
ki-kii=waapam-iko-pan
2-DES.C-see.TA-INV-PRET
'He was going to see you.' (counterfactual reading)

(13) Epenthesis beside coronal /t/ at a morpheme boundary: t+p> tip.[14]

(a) mii appii waa=waapama**tip**an
mii appii waa=waapam-a**t-p**an
EMPH when C=see.TA-2>3-PRET
'That's when you saw him.'
(b) mii appii waa=waapamanki**tip**an
mii appii waa=waapam-anki**t-p**an
EMPH when C-see.TA-1.PL>3-PRET
'That's when we saw him.'

Whatever the analysis, the fact remains that these rules of place assimilation are quite morphologically restricted. There are no general phonological rules which account for more than a few processes (in Saulteaux), and other mechanisms (e.g. morphophonemes, morpheme specific constraints, allomorph listing) must be adopted in order to account for discrepancies between (5) and (13). The relevance of these studies for phonetics is that processes such as (5-7) provide evidence for fortis consonants as underlying concatenations of lenis consonants. These assimilatory processes have their phonetic roots in regressively retiming a supralaryngeal gesture to line up with the voiceless laryngeal gesture of a previous consonant. The most obvious way this process might occur would be through lengthening the supralaryngeal gesture. Thus, we would expect closure duration to be a correlate of the lenis-fortis contrast. If we consider the process in (10), we observe a case of voicing assimilation, since it is triggered by nasals. We would expect voicing to be a correlate at least in fricatives. Although this investigation is limited to stop contrasts, feature economy predicts voicing to be an important correlate across the board (but cf. Jessen 1998 for the difference in featural content between lax-tense stops and fricatives in Standard German).

[14] Bloomfield (1956: 54) noted that "-pan [is] added to –t without connective". In his account allomorph –ipan is used elsewhere.

2.3. A Note on Orthographies

There are two types of orthographies used for Ojibwe; roman and syllabic. Only the roman alphabets are reviewed here since the syllabic does not differentiate between lenis and fortis consonants. Valentine (1994: 164) states that "…Roman orthographies reflect a regional variation in the nature of the fortis-lenis contrast, the Northern orthography representing this contrast as one of preaspiration, or a sequence of h followed by a consonant, and the Southern orthography representing it as a voiced contrast". The "Southern orthography", used in publications by John Nichols and others, is represented as a voicing difference (e.g. Nichols & Nyholm 1991, Kegg 1991). Some of the different orthographies from the main dialect divisions are given below. Recall we have been using Bloomfield's (1956) system till now.

(14) Orthographies for lenis and fortis obstruents (from Valentine 1994: 164).

Southern	Bloomfield	Northern	Algonquin (Maniwaki)	Algonquin (Pikogan)
b	p	p	p initially, b elsewhere	p initially, b elsewhere
d	t	t	t initially, d elsewhere	t initially, d elsewhere
g	k	k	k initially, g elsewhere	k intially, g elsewhere
j	c	c	ch initially, dj elsewhere	tc initially, dj
z	s	s	s initially, z elsewhere	s initially, z elsewhere
zh	š	sh	sh initially, j elsewhere	c initially, j elsewhere
p	pp	hp	p	p
t	tt	ht	t	t
k	kk	hk	k	k
ch	cc	hc	ch	tc
s	ss	hs	s	s
sh	šš	hsh	sh	c

For Saulteaux, linguists have varied according to how they transcribe the contrast. Saulteaux in Saskatchewan is often written with fortis consonants represented like Bloomfield's orthography, but with an <h> instead of the first consonant in the Northern orthography in CC clusters (e.g. Cote 1984, Scott et al. 1995, Logan 2001). This may tell us nothing about the phonetics since, according to Logan (2001), fortis consonants are phonetically long in Saskatchewan Saulteaux (e.g. [p:]). In a pedagogical grammar based on Saulteaux dialects in Manitoba by Voorhis et al. (1976) the distinction is marked with double consonants as in Bloomfield. I myself took introductory and intermediate Ojibwe classes with a speaker from McGregor, Manitoba (Roger Roulette). Nichols' orthography (e.g. b/p…) was used throughout, and we were explicitly taught that the difference was one of voicing. Generally in Manitoba, out of the Roman alphabets[15], the "Southern" orthography seems to be the most widely adopted. It is present in every piece of Ojibwe language material based out of Manitoba since the 1990s that I have been able to find (e.g. Fox 2005, Roulette 1997, Ningewance 2004).

It is not correct, however, that preaspiration is not present at all in the Saulteaux spoken in Manitoba as the adoption of the "Southern" orthography and Valentine's (1994: 164) statement above would suggest. Rhodes & Todd (1981) for instance describe preaspiration as occurring in "some Saulteaux".[16] It is unclear whether this should be taken to mean some speakers or some dialects; but the current study suggests that it occurs some of the time for every speaker but to different degrees (cf. Helgason 2002 for a similar situation with some languages of northern Europe, and DiCanio (2008: 114-5) for San Martín Itanyuso Trique, Zapotec). Valentine (1994:123) states that in the dialects of "northwestern Ontario, and western Saulteaux" fortis obstruents are realized as [^{h}C], and even [$^{\varphi}$p], [^{s}t], [^{x}k], that is a stop preceded by a constriction approximating that of a homorganic fricative". There have been no published instrumental

[15] Syllabics are used in some parts of Manitoba as well (Roger Roulette p.c.).
[16] Hardly any Saulteaux communities were surveyed in Rhodes & Todd's (1981) study.

investigations, besides the present that have attempted to describe or document the state of preaspiration in any Ojibwe dialect (cf. Tallman 2010a for a pilot study with some subdialects of Berens and Saulteaux).

2.4. Discussion

This chapter has reviewed some of the evidence that some linguists have used to argue that fortis consonants are underlyingly consonant clusters at some level of representation. Two types of phenomenon seem to support this idea. First, Ojibwe fortis consonants pattern with consonant clusters phonotactically. This reflects the fact that they are derived from consonant clusters in Proto-Algonquian. Second, phonological alternations that produce fortis consonants involve the assimilation of a preceding segment to the place features of the second lenis consonant in a C_1C_2 cluster. This pattern is either morphologically conditioned in some fashion (as in the third person conjunct -t with the preterit), or else it is extremely morphologically restricted (/t/ final II verbs with the inanimate conjunct marker -k). The fact that mostly coronals regressively assimilate, although most likely categorical, may have a phonetic basis in the inertial motor properties of these consonants in relation to their place cues in flanking vowels. Another phonological alternation occurs at a derivational word boundary and involves the assimilation of a glottal stop to the supralaryngeal place features of the /t/ in the suffix -toon. Despite the lack of detailed instrumental studies, the historical basis of the lenis-fortis contrast (2.1.), the phonological alternations that imply segmental differences (2.2.) and the auditory impressions of various investigators, can give us an idea of what parameters of phonetic encoding are important for making the lenis-fortis contrast in Ojibwe, and hence how our phonetic investigation should proceed.

It is often noted, especially in early missionary descriptions (e.g. Baraga 1850 for Chippewa, Dumouchel & Brachet 1942 for Saulteaux), that fortis consonants are in some sense "strong". Dumouchel and Brachet describe the situation with some fortis consonants (cf. a similar statement in Baraga (1850: P. II, cited in Nichols (1992: xii)):

> "Il arrive souvent que P, K, T aient un son dur. Leur prononciation est difficile à rendre par écrit. Tout ce que nous pouvons indiquer ici, c'est que souvent la prononciation pour P est entre celle du P et du B; celle du K est entre celle du K et du G; celle du T est entre celle du T et du D… Le seul moyen de trouver la prononciation exacte de ces consonnes est d'écouter attentivement les Indiens les prononcer" (Dumouchel & Brachet 1942: 5).

Unlike the lay grammarians mentioned above, Bloomfield was able to correctly capture the phonological distribution of lenis and fortis consonants. Adhering to his phonemic principle (Bloomfield 1926) allowed him to achieve a greater degree of precision than the missionary grammarians that preceded him with repect to the phonemics, however, the phonetics of the contrast still evade precise description:[17]

[17] In fact Bloomfield seems to implicitly relegate phonetic detail to another field of inquiry completely: "… the physiological and acoustic description of acts of speech belongs to other sciences than ours" (Bloomfield 1926: 153). Compare this to the position of contemporary Laboratory Phonology: "Probably the single most important auxiliary theory in our field is the acoustic theory of speech production. This theory relates critical aspects of speech articulation to eigenvalues of the vocal tract, which can in turn be related to peaks in the spectrum…" (Pierrehumbert, Beckman & Ladd 2000: 281).

> "The fortes are voiceless, vigorously articulated, and often rather long. The stops pp, tt, kk, cc are often preceded by a slight aspiration: eto:ppuwin 'table'. The sibilants *ss, šš* are often weakened between the vigorous onset and the vigorous opening, with a clear division into to syllables: ni:ssa:ntuwe: 'he climbs down, descends" (Bloomfield 1956: 8).

Hockett (1939:1) similarly noted that fortis consonants in Potawatomi were "strongly enunciated".[18] Piggott (1980: 57) states that lenis consonants are "basically voiceless and unaspirated, but become voiced, or fortis aspirated, under certain conditions". Piggott does not explicitly discuss the phonetics of fortis consonants, referring to this series as "fortis aspirated" or "phonetically fortis". Nichols (1991: xxvii) transcribes fortis consonants as phonetically long (as in [k:] for **k**) in his pronunciation guide. In a pedagogical grammar of Manitoba Saulteaux, Voorhis et al. (1976: 4-4) considers fortis consonants "double [lenis] consonants" and states that they "always have the voiceless sound" (Voorhis et al. 1976: 3-3) and are "somewhat extended or longer than the single consonants" (1976: 4-4). He notes that lenis consonants are voiceless word initially and voiced intervocallically and before nasals, but that this varies according to rate of speech. Word-finally the only thing that distinguishes lenis from fortis is the length of the fortis consonant (Voorhis et al. 1976: 4-4). Valentine (1994: 123-4) states that the lenis stops are only consistently voiced in Algonquin and in other dialects "at least partially voiced in all environments". Fortis are "typically both voiceless and more or less geminate" (Valentine 1994: 124).

[18] Potawatomi is not considered a dialect of Ojibwe by some authors (e.g. Valentine 1994). Valentine (1994: 100) describes the difference as it pertains to lenis and fortis obstruents: "Reflexes of various PA clusters which show up as fortis obstruents in Ojibwe alternate between fortis and lenis in Potawatomi, the latter occurring in utterance initial positions e.g., nwapma k:we 'I see the woman', but k̲we nwapma initially. Also word final fortis obstruents only show up as fortis before a consonantal sonorant (n, m, w, y), e.g. muk niwapma 'I see the beaver.' vs.niwapma muk."

There is nothing wrong with using the terms lenis and fortis to make reference to a descriptive class whose covariates cover a range of various phonetic features (Malécot 1970, Sils 1970, Kohler 1984, Docherty 1992). However, as a descriptive label that accounts for the details of phonetic implementation in a particular language, the notion of lenis and fortis has been discredited (Catford 1977, Ladefoged & Maddieson 1996).[19, 20]

The only instrumental phonetic study of the lenis-fortis contrast in Ojibwe concluded that it is not one of gemination as the consonant cluster analysis described above would suggest (Swierzbin 2003). This was based on the fact that the difference in closure duration between lenis and fortis consonants in Border Lakes Ojibwe patterned closer to English than languages normally analyzed as consisting of geminates. It was found that so-called Ojibwe geminates are only 1.2-1.4 times as long as their lenis counterparts, closer to the differences between voiced and voiceless consonants in English (1:1.4) and French (1:1.2) (Suen & Beddoes 1974,

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[19] This is not to say that there are no interesting theories of "strength", which describe for allophonic variation (Lavoie 2001), or the inertial motor factors involved in sound change (Kirchner 1998). The latter authors approach the problem from the perspective of the different categorical and gradient processes which effect these consonants both synchronically and diachronically (Kirchner 1998, Lavoie 2001). These are not mutually exclusive approaches but rather methodological starting points for addressing what is very similar and in some cases identical phenomena (cf. Lavoie 2001). Lavoie (2001) bases her theory of strength on a typological survey of languages which she attempts to back up with synchronic phonetic evidence.

Kirchner (1998) provides a cross-linguistic survey of lenition processes and attempts to explain these based on a principle of effortfulness formalized as the constraint [LAZY] in an optimality theoretic approach (Prince and Smolensky 1993). Given that the contrast itself is based on different constraint rankings (Kircher 1998) the theory implicitly makes predictions concerning the phonetic correlates to the contrast in question. The difference arises in the overlapping empirical phenomena that these approaches address. Where as the lenition approaches focus on strength as a phonetic process dependent on many features of phonological contrast and their interrelations, feature-correlate approaches start from the goal of characterizing the nature of an entire natural class. Lenition in the latter case is highly correlated with one of these natural classes (the 'lenis' consonants), but not limited to it.

[20] Note that this principle, about the nonuniversality of the phonetic encoding of labels in phonological descriptions, does not just apply to the lenis-fortis contrast, it applies across the board to all phonological categories: "categories [the phonetic correlates to phonological contrast], defined as relations between a discrete level and a parametric level, cannot be universal. That is the picture of human phonetic resources as pegs in an IPA-like phonetic pegboard cannot be sustained." (Pierrehumbert 2003b: 127).

O'Shaughnessy 1981 respectively, cited in Swierzbin (2003: 346)). Languages with real geminates have ratios of between 1:2 (Esposito & Benedetto (1999) for Italian, Lahiri & Hankamer (1988) for Bengali) and 1:3 (Lahiri & Hankamer (1988) for Turkish). Swierzbin (2003: 346) concludes that "based on these comparisons, it seems that the main difference between fortis and lenis consonants in Border Lakes Ojibwe is that of voicing and not duration". Lenis consonants are "usually voiced when they occur between two vowels and voiceless otherwise" (Swierzbin 2003: 345). However, the degree and type of voicing that marks consonants contrasts varies in systematic ways from language to language (e.g. Keating 1984 for English, French and Polish). This is also the case for consonant duration as well; so-called fortis consonants are 1.5 to 3 times as long as their lenis counterparts (Ladefoged 1996: 91-2), with no discrete break between languages that code a voiced/voiceless contrast or languages that distinguish primarily according to some other correlate. Thus, informal descriptive labels such as lenis-fortis, voiced-voiceless, singleton-geminate etc… do not solve the problem of contrast, they only put it in another domain, even if informed by some instrumental phonetic data.

Hence, previous approaches have not formulated the issue of contrast directly, too readily giving special empirical status to labels which describe only the fact that there is a contrast- not how the contrast is made. Despite this, previous investigations can inform what correlates we consider important for marking the lenis-fortis contrast in Ojibwe. We can be reasonably sure that consonant duration will be a correlate. This hypothesis is based on considerable impressionistic observation and the fact that fortis consonants historically come from consonant clusters. Continued vocal fold vibration during the closure may also be a correlate, since investigators have frequently described the contrast as one based on "voicing" on analogy with the category in

English phonological descriptions, i.e. [+/-voice] (e.g. Kingston et al. 2008 and references cited therein). Every description makes reference to lenis consonants being voiced in certain circumstances compared to fortis consonants which are always voiceless. Postaspiration (Jessen 1998), VOT (Lisker & Abramson 1964) or mVOT (cf. Helgason 2002) are most likely correlates as well, as it is a cross-linguistically common way of distinguishing so-called lenis-fortis sets. Postaspiration is associated with longer voiceless consonant duration for physical reasons as well, in that these consonants have longer intraoral air pressure build up (cf. Stevens 1998). Piggott (1980) also refers to fortis consonants as aspirated in some circumstances as we saw above. Preaspiration has been reported to exist in some Saulteaux (Rhodes & Todd 1981: 58). It is usually described as being obligatory in Berens Ojibwe (e.g. Valentine 1994), but it is generally not thought to be particularly prevalent elsewhere. However, as Helgason (2002) notes, preaspiration can often be fairly subtle and undetectable without instrumental study. It is likely that its cross-linguistic prevalence has been underdescribed.

We might also keep in mind the relevance of the historical development of fortis consonants for understanding the contemporary structure. There is no distinction between lenis and fortis consonants word initially (without syncopation (cf. Valentine 20010)) because there was a constraint in Proto-Algonquian that disallowed consonant clusters in this position. Since there is no lenis-fortis contrast word initially, it makes no sense to analyse contrast in this position. Piggott (1980) posited a rule that turns lenis consonants "phonetically fortis" word initially. However, from the perspective of phonetic interfacing, what we should ask is the extent to which initial consonants pattern with lenis or fortis in terms of their phonetic correlates. It is for this reason that initial consonants are not pooled with lenis or fortis consonants in this study. Only intervocalic lenis and fortis consonants are compared. Word final fortis consonants are extremely rare in corpus data. They are outside the scope of this study.

The rest of this thesis attempts to give a first approximation of some of the quantitative aspects of the correlates of the Saulteaux Ojibwe lenis-fortis contrast with reference to the relationship these correlates share with each other between speakers and places of articulation in some of the Saulteaux dialects of Manitoba. First we describe the theoretical framework that motivates the descriptive parameters used in this study.

3. Theoretical Framework: Probabilistic Phonology

In this section we describe the main hypothesis of this thesis and its relationships to the theoretical framework adopted. This will be important for understanding the modelling choices used in the results section (4.1.3.). We adopt the model phonological structure recently articulated by Pierrehumbert (Pierrehumbert 2001a, 2001b, 2003a, 2003b). Some mention is made of exemplar theory in relation to the theory adopted here.

In this framework phonology is a cognitive architecture that consists of multiple levels of representation. Following Pierrehumbert (2003b: 116) these levels include at least (1) Parametric phonetics: A quantitative map of acoustic and articulatory dimensions over which some notion of proximity and distance can be defined. (2) Phonetic encoding: Categories and category systems that relate linguistic elements (phonemes, distinctive feature, syllables, morphemes etc…) to a k-dimensional phonetic space. (3) The lexicon: Lexical representation of morphemes, wherein lies the symbolic relations between form and meaning. (4) The phonological grammar: General constraints on morphemes in the lexicon based on the combinatorial elements that are encoded at level (2). (5) Morphophonological correspondences: Phonological relationships between classes of morphological forms and processes.

The empirical phenomena related to the lenis-fortis contrast in Saulteaux Ojibwe for the levels (4) and (5) were described in the previous chapter. The main structure of this thesis is on how the contrast is structured at level (2), that of phonetic encoding. The following specific technical definitions of the following concepts are necessary for understanding the discussion below (cf. Pierrehumbert 2003c, Luce 1963):

Category: This defines a density distribution over a particular dimension of the parametric level. It relates an abstract variable to a probability region over some phonetic continuum. Multiple categories can exist on a single phonetic continuum and their statistical properties and relationships can be used to make linguistically relevant distinctions.

For example in a study conducted by Maye & Gerken (2000), English speaking subjects were exposed to various examples along the VOT continuum in a set of experiments. They created synthetic phonetic continuum between /d/ and unaspirated /t/ which are not phonemically distinct in English in the position they examined. One group was exposed to a unimodal frequency distribution and the others a bimodal frequency distribution over the continuum. Subjects' responses in a discrimination test echoed the frequency distributions they were exposed to. Subjects exposed to bimodal distributions had higher discrimination near the boundaries of the distributions they were exposed to, while subjects exposed to unimodal distributions did not. In the terminology we are developing here, the former group acquired two categories and the latter acquired only one on the VOT dimension.

A frequency distribution of VOT values a speaker associates with a particular phoneme is an example of a category. An example of categories encoded along the same dimensions is given from my own data from Saulteaux in figure 1a and 1b. The data are from the dental/alveolar lenis and fortis stops of the speaker Boo from Long Plain. The following plots demonstrate four categories associated with two different phonetic continua. A and B are each separate density distributions over the closure duration parameter (figure 1a) and C and D are each separate density distributions over the postaspiration (or mVOT, cf. 4.1.2.2. below) parameter (figure 1b), despite the fact that they overlap. A category refers to regions in these dimensions not individual points.

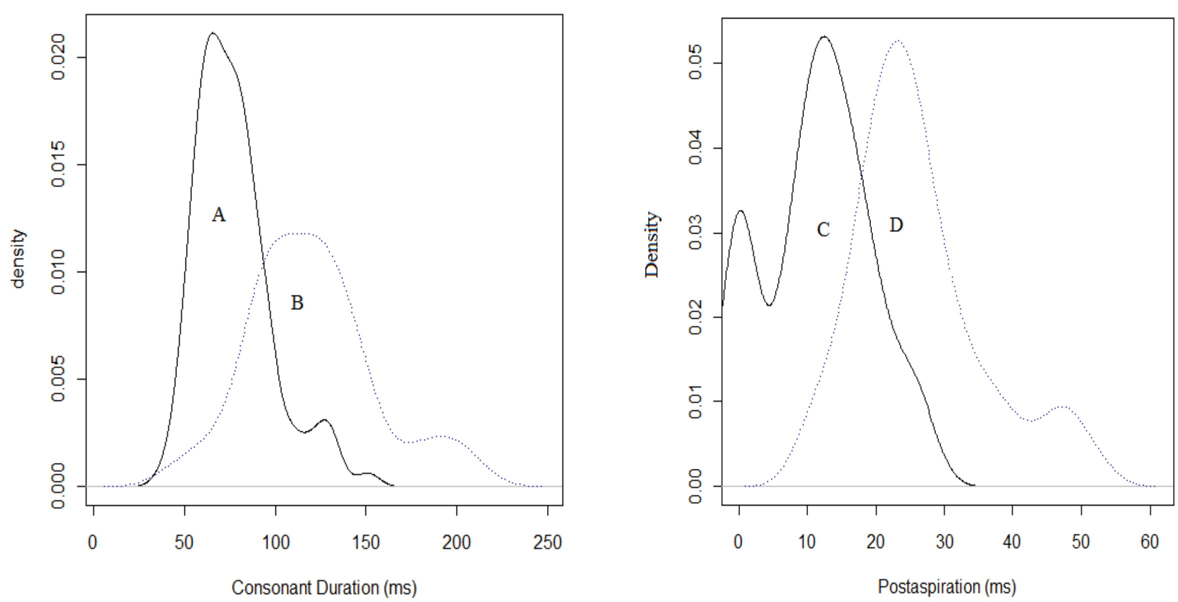

Figure 1. a. Consonant duration in ms for the speaker Boo from Long Plain. A is a density distribution for the values associated with lenis /d/. B is a density distribution for the values associated with fortis /t/. b. Postaspiration in ms for the speaker Boo from Long Plain. C is a density distribution for the values associated with lenis /d/ and D is a density distribution for the values associated with fortis /t/.

Category System: I use the term category system to refer specifically to a label that defines a set of categories or distributions.[21] Thus, because phonemes encode multiple phonetic dimensions they are examples of category systems. Elaborating on the tutorial plots above, a category system could define the set of categories {A, C}, another {B, D}. Category systems define regions in a k-dimensional phonetic space rather than along just one parameter as in simple categories. Hence the category systems for the sets {A, C} and {B, D} have two dimensions associated with them. This situation is represented in the following figures 2a and 2b. Specifically the figure 2a could represent /d/ and the figure to the right fortis /t/ given closure duration and postaspiration assuming these are the only correlates to these phonemes.

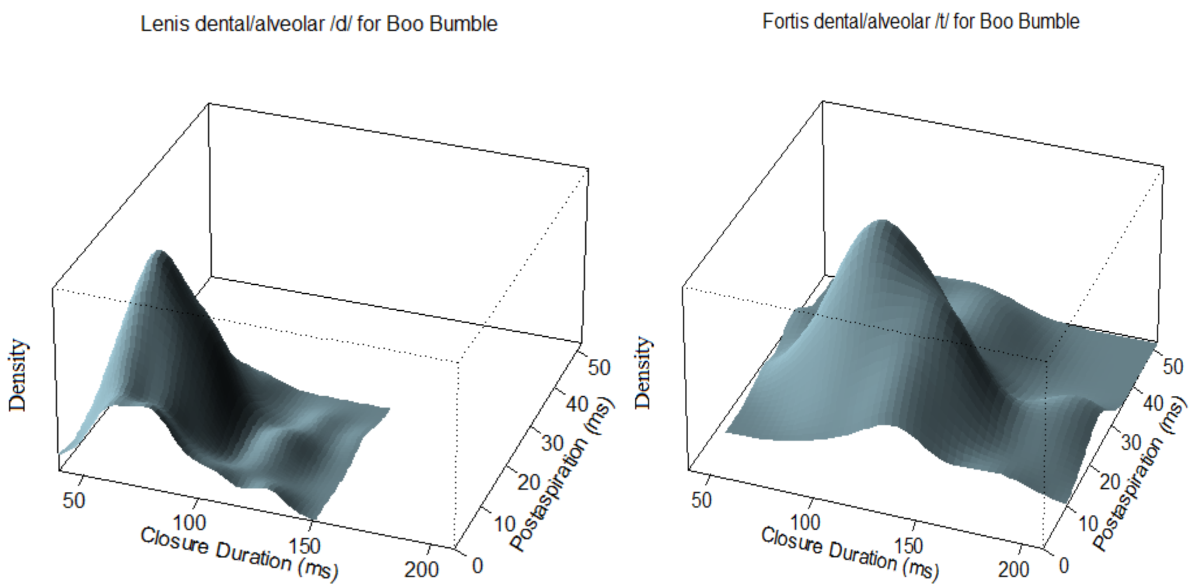

Figure 1a (left). Two density distributions for the phoneme /d/ on the closure duration and postaspiration parameter. 1b (right). Two density distributions for the phoneme /t/ on the closure duration and postaspiration parameter.

[21] In much of the categorization literature it is customary to refer to what I call a "category system" as a "category" (e.g. Rosch & Mervis 1975, Pothos & Close 2008) with multiple dimensions.

The tutorial plots above belie the fact that phonemes are never composed of just two dimensions. Many more correlates have been shown to be used by speakers to distinguish phonemes even in minimal pairs (Lisker 1986). The actual phonetic space of a particular unit of phonetic encoding can never be displayed graphically because it is too high-dimensional. These units map onto regions in a k-dimensional phonetic space (Pierrehumbert 2001b, 2003b).

Contrast Precision:[22] This refers to how well a particular density distribution (category) is able to predict a particular category system in contrast to others with reference to one or more dimensions of phonetic space. Intuitively contrast precision increases as the density distributions on a particular parameter get further apart and/or overlap less. As categories get closer together their contrast precision for a particular complex category decreases (cf. Pierrehumbert 2001a, Kirby 2011). Informally the contrast precision of category A for the category system {A, C} in the figures above is defined by how much overlap it has with B in the consonant duration dimension. If the category systems {A, C} and {B, D} were placed on the same plot contrast precision would extend to this case as well. Thus, it can be viewed both as a property of categories in isolation and category systems as a whole. It is important to point out that contrast precision cannot be equated with the distance between particular points. It is difficult to explain this aspect of contrast precision with reference to the figures above, so we use the invented categories below.

[22] This term is not used by Pierrehumbert (2001b, 2003b). It is borrowed from Kirby (2011), although he does not give it an explicit definition. For Pierrehumbert (2001, 2003c), and most likely for exemplar theorists in general, this concept would be subsumed under the relationship between statistical choice rules in relation to complex categories in perception (Luce 1963, Krushke 1992) and in production (Pierrehumbert 2001b).

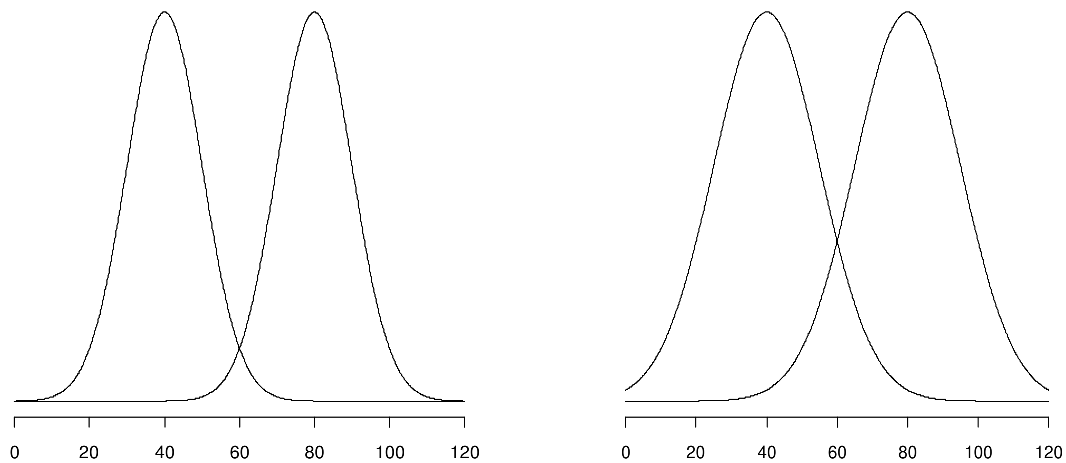

Figure 3a (left). Hypothetical density distributions with mean 40 and 80 and standard deviations 10 each. 3b (right). Hypothetical density distributions with mean 40 and 80 and standard deviations of 20 each.

All of the density distributions in figures 3a and 3b have the same means (40 for the left, 80 for the right) but different standard deviations (a=10, b=20). The distance between the means of the categories on each dimension is the same but the degree to which the categories overlap is different. In figure 3b the categories overlap more than in figure 3a. We, therefore, want our measure of contrast precision to capture this difference. That is, contrast precision should quantify the separation of categories in relation to their width (Pierrehumbert 2001b: 208).

Generally literature on phonetic typology has demonstrated that where contrast precision is diminished in one dimension it is increased in another (Pierrehumbert 2003b, Kirby 2011). For example, Engstrand & Krull (1994) demonstrated that Swedish and English vowels show more broad and overlapped phonetic distributions for length than Finnish vowels. This can be attributed to the fact that in Swedish and English vowel quality and vowel length function together in a system of vowel categories, whereas Finnish has a pure length distinction with extremely little impact on vowel quality. Swedish and English have category precision dispersed along three parameters for the relevant contrast, but for Finnish vowel duration has higher category precision to the detriment of other parameters.

Another example is from the aspirated-lenis obstruent contrast in Korean. In Korean VOT was identified as the most reliable correlate of the contrast between aspirated and lenis stops, with aspirated stops consistently having a higher VOT value (e.g. Han & Weizman 1970). F0 (pitch) covaried with the distinction, but was not described as the primary cue to the lenis-aspirated contrast. In a recent study done with a younger generation of speakers, Kang and Guion (2008) found that VOT was nondistinctive, and F0 was a better covariate to the pair. Thus, heightened category precision along the F0 dimension corresponded to a lowering of precision on the VOT dimension for the younger generation of Korean speakers (cf. Kirby 2011 for an "enhancement" model that accounts for this change).

In this thesis I attempt to quantify/model contrast precision between lenis and fortis stops along certain dimensions of the quantitative parametric phonetic space. A hypothesis that this thesis attempts to corroborate, on the general lines of the studies described above, is that although the contrast precision along each particular parameter may vary from speaker to speaker, the contrast precision between category systems as some function of all their dimensions considered together should be approximately the same. Framed with reference to our topic, although Saulteaux speakers vary in terms of how they use acoustic correlates to mark the lenis-fortis contrast, overall the contrast has close to the same degree of robustness from speaker to speaker.

In this study we are able to quantify contrast precision for the lenis-fortis distinction by inferring density distributions from frequency distributions in the database.[23] Thus, a simplifying assumption is made in this thesis in order to investigate precision contrast. We assume that the frequency distributions of the acoustic correlates found in our corpus data for lenis and fortis stops can adequately represent the density distributions in the phonetic encoding of these consonants for each speaker. The phonetic encoding of a contrast is not just used for production, however, it is also used for perception. Obviously a speaker's ability to weigh perceptual cues, however, need not be completely a function of their production; in fact it is clearly not this simple (Foulkes & Docherty 2006). Ideally a study such as this should be supplemented by data from perceptual studies centred on the relevant acoustic correlates in relation to the categorization of lenis-fortis stops. We tentatively assume that the supposition that frequency distributions from production are adequate for describing phonetic encoding is justified by the success of exemplar theory. Exemplar theory claims that categories are maintained and updated by incremental updates based on exemplar tokens of those categories (Johnson 1997, Pierrehumbert 2001b, 2003b). Pierrehumbert (2003b: 186) explains the relationship between phonetic encoding, perception and production based off this theory:

> "Once a label is selected (presumably through a decision to say a word that involves that label), a production goal is established by sampling the empirical distribution for that label. Specifically, an averaged neighbourhood around a randomly-sampled point in the distribution serves as a production goal."

[23] A number of methods are used for this (cf. 4.1.3.)

Thus, the statistical distributions serve as the primary data for the phonetic encoding of category systems for the language learner. Analogously, we hope that these statistical distributions in corpus data can serve as the primary data for the linguist attempting to understand this system.

4. Phonetic Encoding I: Methodology

Section 4.1. describes the speakers and data collection method for this study. The next section 4.2., describes how the acoustic correlates were measured with reference to spectrograms and wave forms. Problems with the methodology and how I attempted to cope with them are noted in each section. The final section describes the probability models used to quantify the concept of contrast precision defined in the previous chapter.

4.1. Speakers and Data

Ojibwe is spoken throughout a wide geographical area extending from western Quebec into Alberta (figure 4). The speakers for this study were all from Manitoba and thus fall within the Saulteaux dialect, according to classifications in the literature (e.g. Rhodes & Todd 1981, Valentine 1994, 1996).[24] The six Saulteaux speakers represented in this study are from Fairford, Lake St. Martin, Brokenhead, Peguis, Sandy Bay and Long Plain (figure 5). The exact age of all

[24] However, it appears that dialects in northeastern Manitoba closer to the Ontario border should be regarded as different dialects. Voorhis et al. (1976: vi) states that "the language spoken around Island Lake and Red Sucker Lake in Manitoba, and in adjacent parts of Ontario, though often called Saulteaux or Ojibwa, and just as often called Cree, is really different enough from all of these [Saulteaux dialects of Manitoba] that is is hard for both neighbouring Saulteaux and Cree speakers to understand it" (cf. Wolfart 1977, Wolfart & Shofel 1977).

the speakers is not known, although from the stories they tell it sounds as if they are approximately middle age.[25] All the speakers in this study are fluent in Saulteaux.

The data for this study came from three different sources. The first was from elicitation with a speaker from Long Plain. The data obtained this way are naturally more controlled. Recordings were made in Portage la Prairie Manitoba. Data for the speakers from Fairford, Sandy Bay, Lake St. Martin and Brokenhead all came from recordings from the Treaty #1 Oral History Video Project.[26] The data from the speaker from Peguis were obtained from Rand Valentine's Ojibwe website (Valentine 2010). The data obtained from Valentine's website were recorded in 1983.

The data obtained from the Aboriginal Languages of Manitoba Cultural Centre (henceforth ALM) consists of interviews that Roger Roulette conducted in the 1990s with various speakers of Ojibwe for the Treaty #1 Oral History Video Project (Roulette 1997). These were recorded on video by Roger Roulette and then converted to wav files by the current researcher. The interviews are fairly informal. Permission to use these recordings was obtained from ALM. Sometimes English words are used for place names or in certain expressions, but generally the use of English is negligible. Transcripts were all written by Roger Roulette, using the Fiero orthography. Mistakes in the transcription were corrected by the present researcher, although this was fairly rare. The recordings vary in terms of their quality. Interviews that contained predictable background noise (some feedback, refrigerator etc...), that did not seem to interfere with the measurements were used.

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[25] Joseph Bealieau (Sandy Bay) tells a story from the 1940s for instance: Twenty eight days imaa ngii-anokii bwaashka`iganing, aazha four dollars a day gii-diba`igem. That was, aazha thirty years old iwapii. Ngoji iidog, 1941, 42 ngoji imaa.

[26] Much thanks go out to Aboriginal Languages of Manitoba for allowing me to use these recordings.

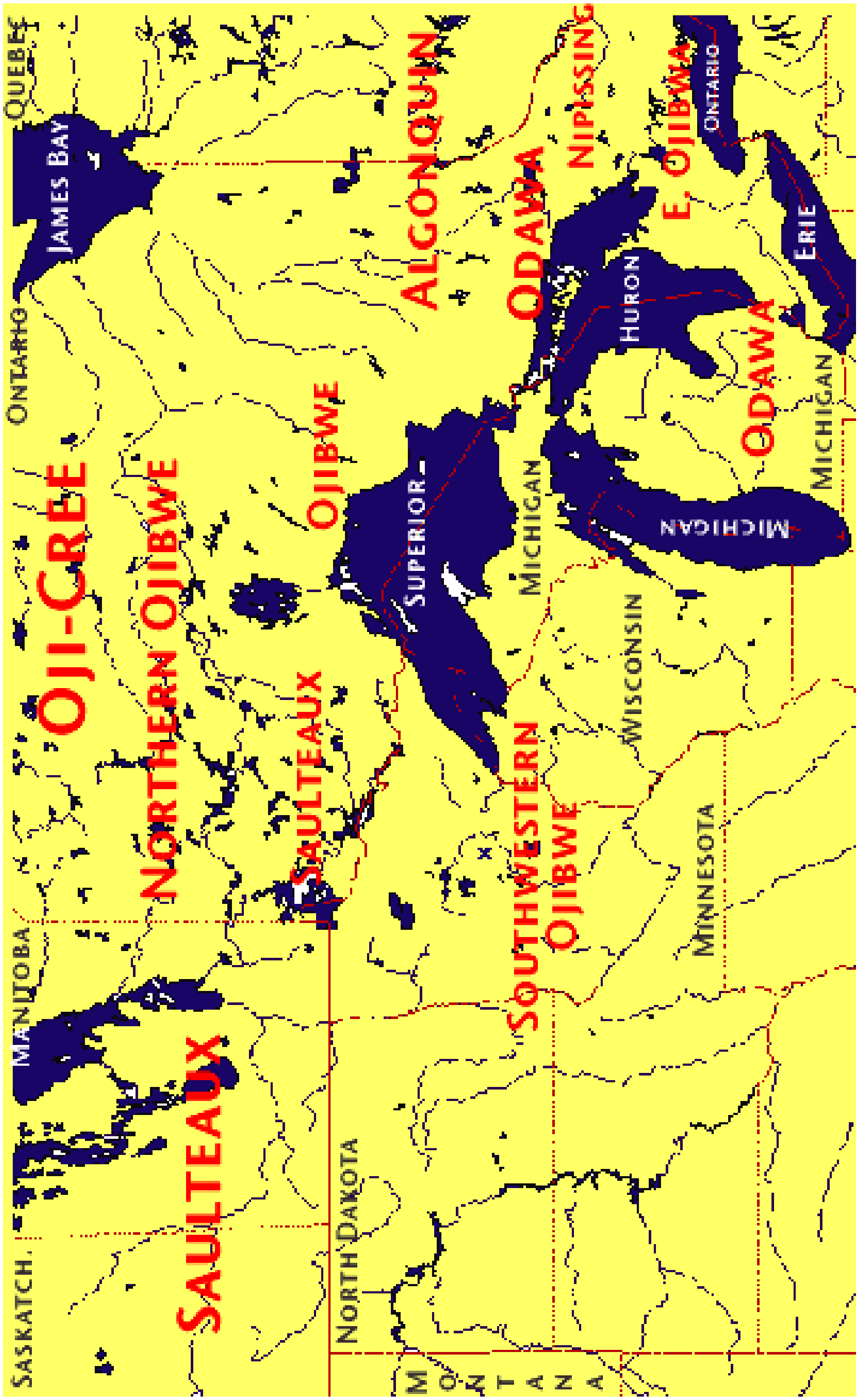

Figure 4. Ojibwe dialects (from Valentine 2010)

Figure 5. Rough location of Saulteaux speakers in Manitoba used in this study.

I obtained the data from Long Plain through elicitation. Two word lists were constructed. One was meant to elicit general phonological attributes present in the dialects. This was based on material presented in Valentine (1996). Another word list was constructed to obtain controlled tokens of lenis and fortis stops. [27]

[27] The construction of a word list was a fairly complex process. The reason for this was that the word list was constructed out of dictionaries from all the dialects (Baraga 1886, Rhodes 1985, Nichols & Nyholm 1991, et al.). It was expected that many of the words would be infrequent or nonexistent in my consultant's dialect, so the word lists had to be large in order to account for this. Also it is difficult to not confound affects from phonological environment and morpheme specific phonetics in agglutinating languages such as Ojibwe.
The phonological environment controlled for in the database was all words where these stops occurred between low front vowels (a_a, aa_a, a_aa, aa_aa). A pilot study was done using an online Ojibwe dictionary found that this was the environment where the most of the lenis and fortis stops could be compared (Tallman 2010c). A preliminary database was then constructed which encoded phonological specifications (surrounding vowels and consonants, number of syllables, stress position) and information about morphological decomposition. The idea was that one could use such a database to construct word lists with comparable phonological environments whilst controlling for morphology. Controlling for morphological decomposition was felt to be necessary because derivational morphology is extremely productive in Ojibwe (e.g. Rhodes 1976). Thus, morphological structure ought to be

The consultant preferred to use words in elicited sentences rather than in carrier phrases. The process was repeated 5-10 times with each word. Sometimes, the consultant produced some tokens at an abnormally slow pace to help the current investigator hear what he was saying during some sessions. These tokens were removed from the database.

Thus, the data were obtained from different sources with different methods of collection. This should be kept in mind during the presentation of the acoustic data. The distinction between the corpus data and noncorpus data will probably be reflected in differences in hypo to hyper articulated speech (cf. Lindblom 1990). In the latter case (hyper speech) the acoustic correlates might be exaggerated. Moon and Lindblom (1994) for instance found that vowel undershoot was much less prevalent in citation-form speech. The information on speakers and recordings is summarized in (15).

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controlled for to avoid confounding contextual allophony with morpheme/word specific phonetics (Hay 2000, Pierrehumbert 2002). Although this was not obvious to the present researcher at the time, it seems that such a problem is much more difficult to resolve in Saulteaux Ojibwe than in nonagglutinating languages. The reason for this is that there is such a tight relationship between phonological environment (at least in terms of surrounding vowels and consonants) and morpheme in Ojibwe. In consequence, specifying subsets of phonological environments in the database was often no different from asking for all the words that contained a particular morpheme (90% of /at/ sequences come from the final –batoo 'run') (Tallman 2010d, 2010e).

These problems aside, word lists were still constructed, although their degree of control came down to specifying the quality and length of the previous vowel. In the end all tokens of lenis and fortis consonants from elicitation were used. Information about phonological environments was specified directly in the database with the acoustic measurements. In principle, a degree of control could be achieved through sheer sample size and subsetting. One can specify subsets of data by referring to the database which contained the acoustic measurements directly. For example if one wanted to only compare the length of a previous vowel with /a/, then one could specify a subset of the data that contained only tokens that met that criterion. In this case we still have to check to see if there is enough tokens for the statistical models to be meaningful and whether there might be confounding effects involved (such as phonological environment and morphological context symmetry).

(15)

Speaker	Reserve	Style	Linguist	Year	Signal-to-Noise (dB)
NT	Peguis	Story	Valentine	1983	42
Boo	Long Plain	Elicitation	Tallman	2010	35-40
MR	Fairford	Conversation	Roulette	1997	24
WM	Lake St. Martin	Conversation	Roulette	1997	28
JB	Sandy Bay	Conversation	Roulette	1997	30
SF	Brokenhead	Conversation	Roulette	1997	32

Although the signal to noise ratio was quite low for some of the recordings, this did not interfere much with the measurement of durational correlates (preaspiration, consonant duration, postaspiration, previous vowel duration). However, it was difficult to measure the duration and intensity of voicing during the consonant closure. The first reason for this is that the background noise in many of the recordings from the Treaty #1 History involved low frequency feedback, which was in certain circumstances, difficult to differentiate from voicing. The second reason that voicing duration during the closure was difficult to measure was that the recordings were not made in a soundproof room. Thus, it was difficult to tell where the offset of voicing was during a closure because of the possibility of confounding it with echo from the previous vowel (cf. Helgason 2002).[28] The next section discusses the segmentation and measurement criteria used in this study in more detail.

[28] Helgason (2002) actually considers this a problem for measuring preaspiration. Close inspection of the wave form shows periodicity for the echoed signal, demonstrating that it is not glottal frication. However, the distinction between voicing and echoed sounds is much more difficult to make.

4.2. Measurement

This section describes the methodology employed in measuring the acoustic correlates analysed in this study: Consonant duration (4.2.1), postaspiration (4.2.2), preaspiration (4.2.3), and voicing (4.2.4). In the latter case an ordinal value was obtained from inspection of the waveform.

Only intervocalic lenis and fortis stops were measured in this study. The criterion for deciding whether a consonant was lenis or fortis was based on its transcription. In cases where I suspected there might be a mistake the transcription was checked against its spelling in an Ojibwe dictionary (Rhodes 1985, Nichols & Nyholm 1992, Ningewance 2010, et al.). This practice was justified because, with respect to phonology, Ojibwe dialects are thought to vary mostly subphonemically (Valentine 1994). The only case where there was any confusion regarding the transcription was with the word baapaase 'wood pecker', which had been variously transcribed as baabaase or baapaase. The reason for this might be due to occasional vocal fold vibration (voicing) seeping into fortis bilabials, which are generally voiceless. Cases where the class of the stop could not be determined were removed.

All acoustic measurements were made in Praat (Boersma & Weenink 2007) from wav files. The segmentation was done by hand using some of the criteria from Olive, Greenwood & Coleman (1993). For the spectrograms the dynamic range was 35 dB throughout the analysis and the window length was set at 0.005 s.

4.2.1. Consonant Duration

In this study consonant duration refers to the length of the steady state period produced by an occlusion in the vocal tract. In the case of unaspirated stops this occlusion is measured as the period of silence between two periodic waves or stages of glottal frication. The majority of fortis consonants displayed this characteristic (figure 6).

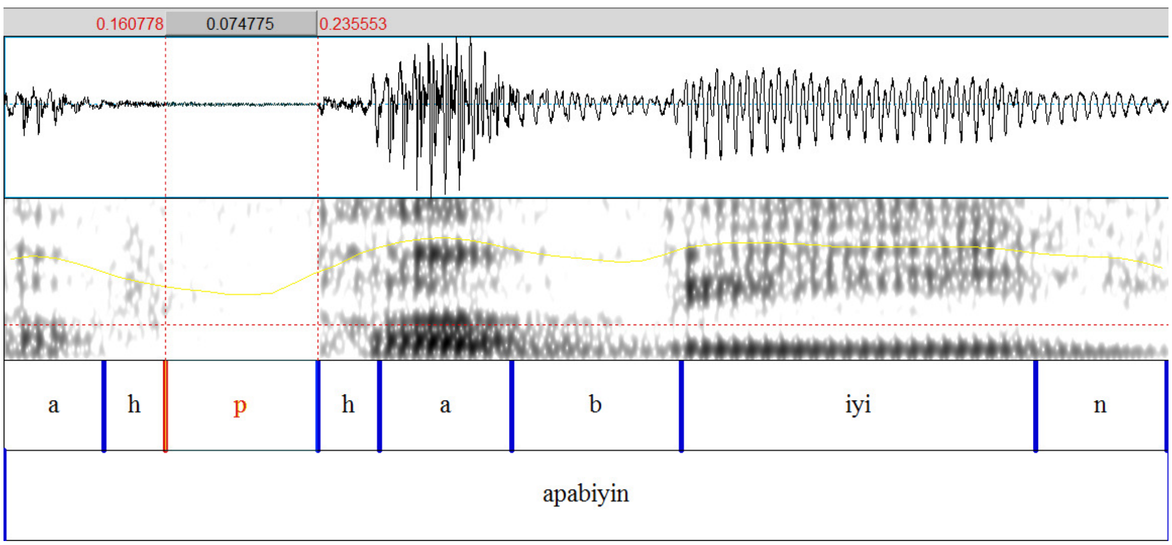


Figure 6. *Spectrogram and waveform of the word apabiyin 'seat' produced by Boo (B.0496) from Long Plain. The* closure duration of the fortis /p/ is approximately 75 ms.

It is not uncommon for some periodic energy (voicing) to seep into fortis consonants, however (cf. Stevens 2000: 333, for a description of this phenomena in voiceless stops). This voicing is generally much weaker in amplitude than in stops described as "voiced", and so in this case the segmentation criteria are based more on spectral discontinuity rather than period of silence per se. Sometimes it was difficult to tell whether a periodic wave during the closure was periodic voicing continuing from the previous vowel or echo from the previous vowel. The latter problem can only be completely resolved if recordings are made in a soundproof room, however the difference is often obvious when we inspect the shape of the wave (echo is a smaller amplitude version of the previous vowel whereas voicing during a closure has other attributes associated with the resonators involved).

Ojibwe lenis consonants are often described as "voiced" intervocalically (Bloomfield 1946, Swierzbin 2003). The F2 onset, offset and inflection points were used for segmenting boundaries between periodic vowels and voiced/lenis consonants, as well as sharp discontinuities marked by the amplitude of the wave form surrounding the intervocalic stops. For bilabials and dentals this criterion was almost always reliable. F2 is only weakly visible during the closure period. Segmentation of a segment with vocal fold vibration during the closure is given in figure 7.

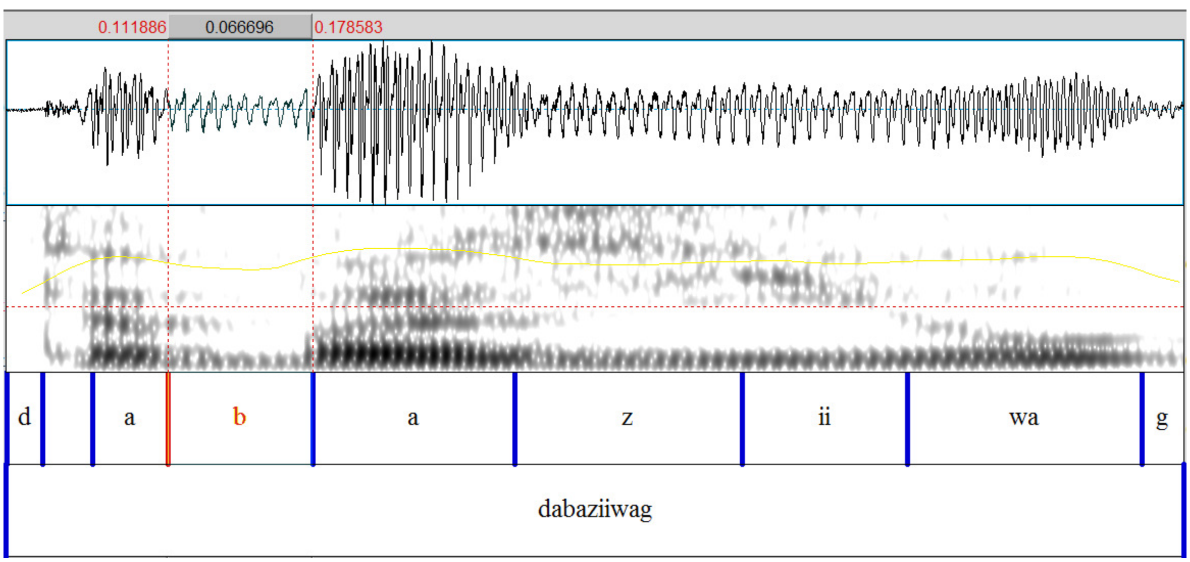


Figure 7. *Spectrogram and waveform of the word dabaziiwag 'they flee' produced by Boo (B.0401) from Long* Plain. The closure duration of intervocalic lenis /b/ is approximately 67 ms.

There is one consonant in this study that is not always easily measurable using the criteria described above. The velar lenis stop /g/ is often undershot so much that the spectral discontinuities between it and its flanking vowels become more subtle. It is often only distinguishable from its flanking vowels by slight drops in intensity, changes in the shape of the periodic wave and 'velar pinch' (Olive et al. 1997: 85). Thus, lenis velar /g/ often has visible formant structure a sign that it is becoming more like an approximant in certain contexts (Lavoie 2001: 81), at least in the hypospeech of some Saulteaux. An example of this is given in figure 8.

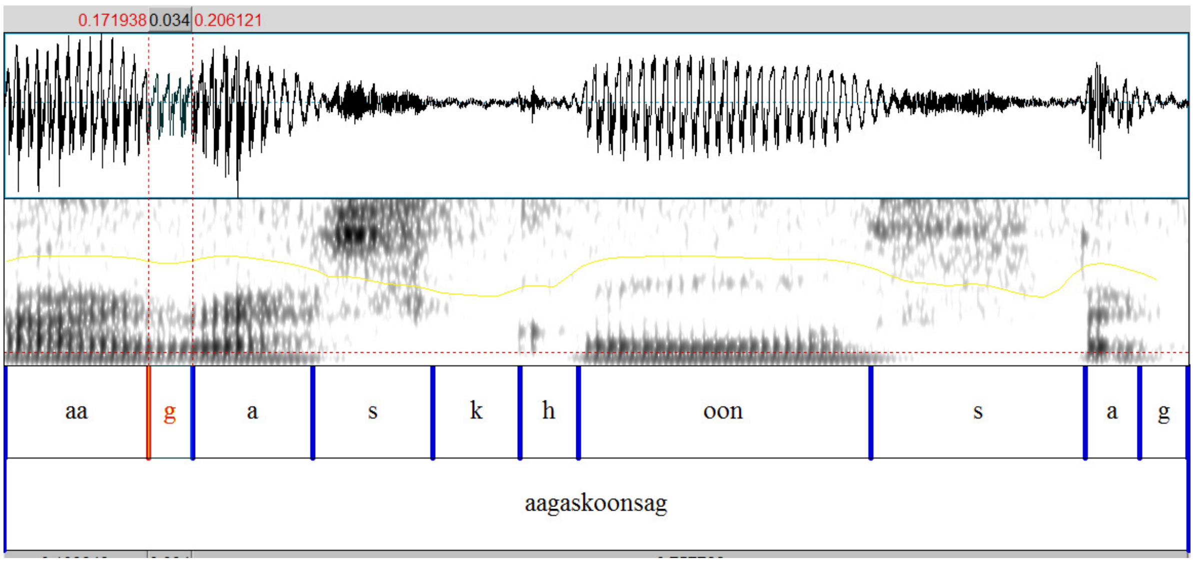


Figure 8. Spectrogram and waveform of the word aagas*koonsag 'little prairie chickens' produced by Boo (B.0333)* from Long Plain. The closure duration of intervocalic lenis /g/ is approximately 34 ms.

The reduction of voiced lenis /g/ to an approximant velar [ɰ] is a cross-linguistically common direction of lenition (Lavoie 2001: 36-7). In many cases /g/ is so undershot that there is no discernible boundary between it and the flanking vowels, either because the FFT is unable to notice any differences, or I am unable to observe any spectral discontinuity. In such situations the closure duration was recorded as 0 ms. Lenis velar undershoot in hypospeech is particularly prevalent in the speakers from Sandy Bay, Long Plain and Brokenhead, and especially in the latter two because the measurements were made from conversation. Details are discussed in the section on velar contrasts (5.3.).

4.2.2. Postaspiration

In this study postaspiration refers to the duration of glottal frication produced after the release of the stop. Voice onset time (VOT) appears to be the most common measurement for aspiration after the release of the closure. It is measured as the time between the release of the closure and the onset of periodic voicing (Lisker & Abramson 1964). VOT can receive a negative value if voicing begins or persists before the release of the closure. There are a few other measurement criteria used in the literature for obtaining aspiration duration values more directly. One can measure the beginning of F2 after the release of the consonant (e.g. Jessen 1998: 76). A distinction is sometimes made between voice onset time (VOT) and modal voice onset time (mVOT). There is often a period of breathy voice in the transition between the aspiration burst and the onset of modal voicing (Helgason 2002: 109). Thus, one can measure the duration of glottal frication produced after the release (figure 9). In many cases there is no difference between VOT and mVOT. It is important to note, however, that they can potentially represent different dimensions of the phonetic hyperspace. In Hindi, the difference between aspirated and breathy stops is primarily a difference in VOT and mVOT (Dixit 1987). In this study we measure mVOT, since it was found that significant and consistent release bursts were made after some voiced lenis consonants in certain contexts. Also it is more comparable with preaspiration because this measurement almost always includes a certain degree of breathy voice (cf. Helgason 2002).

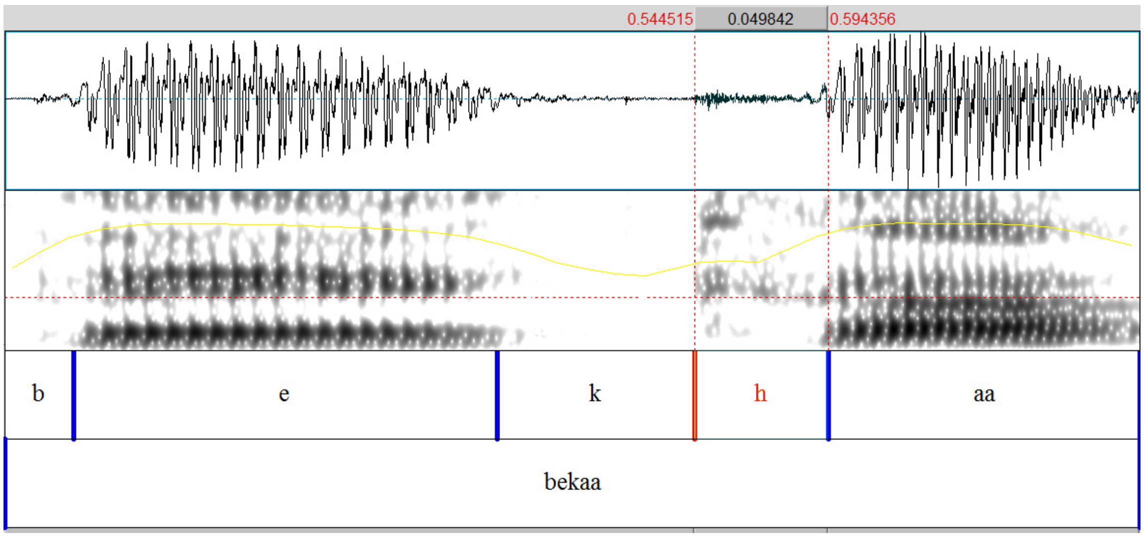
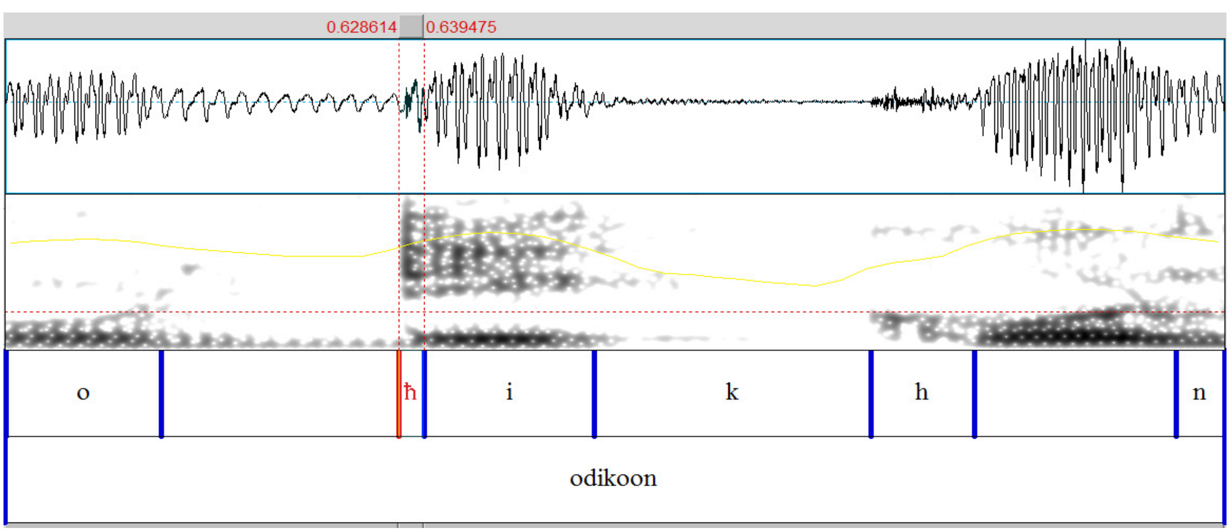


Figure 9. *Spectrogram and waveform for the word bekaa 'wait' produced by Boo (B.0276) from Long Plain.* The duration of the aspiration is approximately 50 ms.

So called fortis consonants tend to be described as having longer postaspiration than their lenis counterparts cross-linguistically (Cho & Ladefoged 1999).[29] It is essentially unproblematic to measure, unless the following vowel is syncopated. Figure 10 below emphasizes the fact that we are measuring the duration of glottal frication as opposed to the duration of voicelessness. Lenis alveolar/dental /d/ is aspirated in a fair number of contexts even when it is voiced (cf. 5.2. for more details).



[29] Excepting of course Korean, where fortis stops are contrasted with aspirated stops in a three way opposition between fortis, aspirated and lenis (e.g. Kim et al. 2010).

Figure 10. *Spectrogram and waveform for the word odikoon 'branch' produced by B*oo (B.0366) from Long Plain. The duration of the breathy aspiration in lenis alveolar/dental /d/ is approximately 9 ms.

In cases where there is an mVOT lag generally the voicing has died out before the release for lenis /d/. This is discussed in section 5.2.

4.2.3. Preaspiration

In this study we measure the duration of preaspiration associated with fortis stops. It refers to a period of glottal frication before the onset of the closure of the stop. In some sense it is the mirror image of postaspiration, however, for stop consonants it lacks a downstream noise source and therefore does not have a "burst" associated with it. The noise is generated exclusively at the larynx (Kingston 1990, Silverman 2003). It appears to be very rarely described as a subphonemic mechanism for maintaining contrast (cf. Helgason 2002: Ch. 2), unlike postaspiration. Interestingly after reviewing the literature on the preaspirating languages in the UPSID database (of which there are only 5, cf. Maddieson 1984), Helgason speculates based on Bloomfield's (1956: 8) description of Eastern Ojibwe (already quoted above) that "it is possible that Ojibwa has (or at least had) non-normative preaspiration very similar to that in [Central Standard Swedish] today... rather than the normative kind found in Icelandic and Faroese" (Helgason 2002: 26).[30] This is quite true for Saulteaux Ojibwe today, as we will see.[31]

[30] A normative correlate for Helgason (2002) is one that is always associated with a particular segment, non-normative refers to one that is variably associated with a segment. Thus, as a correlate begins to appear with a stop closer to 100% of the time, we can say that it is approaching normativity.

[31] In more Northern dialects of we might speculate that preaspiration is much closer to normative (in Helgason's 2002 sense), based on impressionistic descriptions of Berens and Northern Ojibwe (Wolfart & Shofel 1977, Rhodes & Todd 1981, Valentine 1994) and my own auditory impressions of recordings from Paungaasi and Pikanjikum (Berens). Recall that in these dialects fortis consonants are marked with a preconsonantal <h> orthographically. Rhodes (2006) considers this the more conservative system describing "proto-Ojibwe" as having hC clusters.

Preaspiration is measured with voice offset time (VoffT) (e.g. Pind 1995). This refers to the delay between the offset of periodic voicing and complete silence associated with the onset of the closure. Just as with postaspiration a distinction can be made between modal voice offset time (mVoffT) and voice offset time (VoffT) (Kingston 1990, Helgason 2002). The former refers to the period where there is no modal voicing, i.e. where there is breathy voicing, between the vowel and the onset of the closure. The distinction is often not made in the literature because it is thought that “full voice offset does not have to occur to achieve a preaspiration percept” (Helgason 2002: 107) (cf. Ní Chasaide & Gobl 1993 as well). Kingston (1990: 419) actually found that the duration of total lack of periodicity was longer in proportion to the breathy phonation portion for focused words in Icelandic. Following Helgason (2002) complete voice offset is not used as the only criteria for preaspiration in Ojibwe. It seems that the measurement criteria used in the present study might be more conservative than Helgason’s (2002) however. To measure any acoustic value we have to make reference to some threshold (Docherty 1992). In this study we use the spectrogram to assess the boundary of preaspiration. Where there is more clearly random spectral energy in frequency zones not associated with formant bands, i.e. high frequencies, this portion is considered to be part of the preaspiration measurement. Otherwise the waveform is used to measure the onset of preaspiration. For a more detailed study that focused just on preaspiration, one could chart the time course of the amplitude of the harmonics of the preceding vowel in order to assess more precise differences in laryngeal timing (cf. Blankenship 1997). A coarser measurement technique is used for this study because I am attempting to document more general patterns of the phonetic encoding of the lenis-fortis contrast.

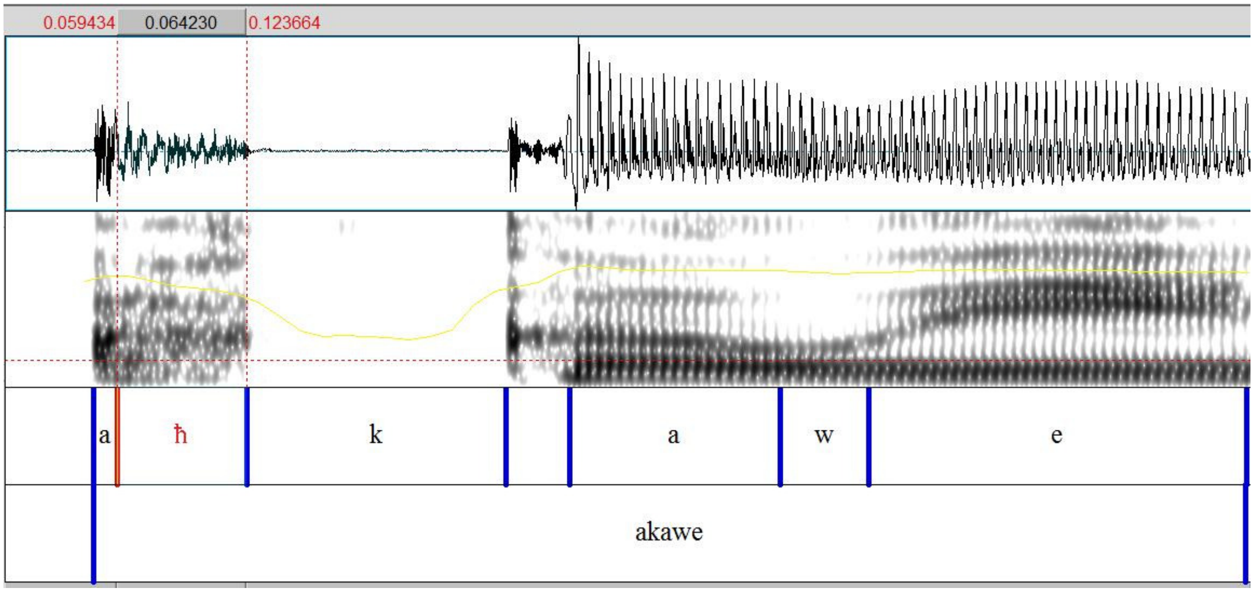


Figure 11. *Spectrogram and waveform for the word akawe "first" produced by Nancy Thompson from Peguis. The* portion of preaspiration is approximately 64 ms long. The frication period is still periodic to a certain extent, and the vowel still has a fair amount of breathy voice.

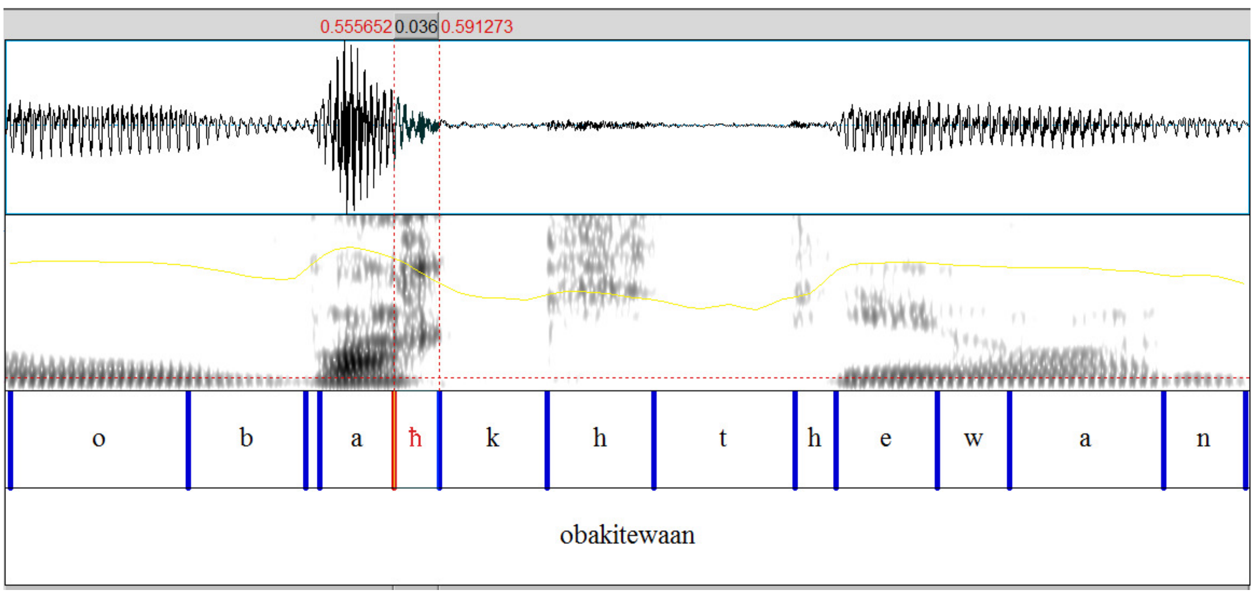


Figure 12. *Spectrogram and waveform for the word obakitewaan 'He hits him' produced by Boo (B.0028) from* Long Plain. The duration of the preaspiration is approximately 36 ms long. Near the end of the preaspirated portion there is almost no periodicity.

The measurement criteria used in this study is exemplified in figure 11 from NT and figure 12 from Boo. Despite the fact that there is a high amount of breathiness in the vowel preceding the fortis /k/ in figure 11 it is not counted as part of the preaspiration duration because the formant is clearly darker than the noise. In the preaspirated portion, however, although periodicity persists, the noise is mcuh darker than the formant bands. Figure 12 exemplifies a greater degree of spectral discontinuity between the vowel and preaspiration, which is present in most cases where preaspiration is observable.

4.4.4. Voicing

Voicing refers to low energy periodicity produced during the closure period of the stop (Ohala 1983). Where periodic voicing is not present during the whole duration of the obstruent a distinction can be made between voicing that leaks into the onset portion of the stop from the preceding vowel or voiced segment and voicing that is related to the following vowel or voiced segment. The latter is referred to as prevoicing (van Alphen & Smits 2004). Prevoicing does not seem to exist in Saulteaux. All cases where glottal vibrations are not present during the whole closure period trail from the onset. An example of this is given in figure 13.

Apart from this, three parameters of voicing ought to be considered. One which is sometimes given is “voicing count” (Tallman 2010a, Holton 2001) where the number of voiced segments is counted in a corpus or elicited speech production. This measure is rather crude since it does not account for variation in terms of the degree of voicing present in obstruents. It has been used to provide a quick glance at whether voicing can be considered "controlled" or not (Holton 2001).

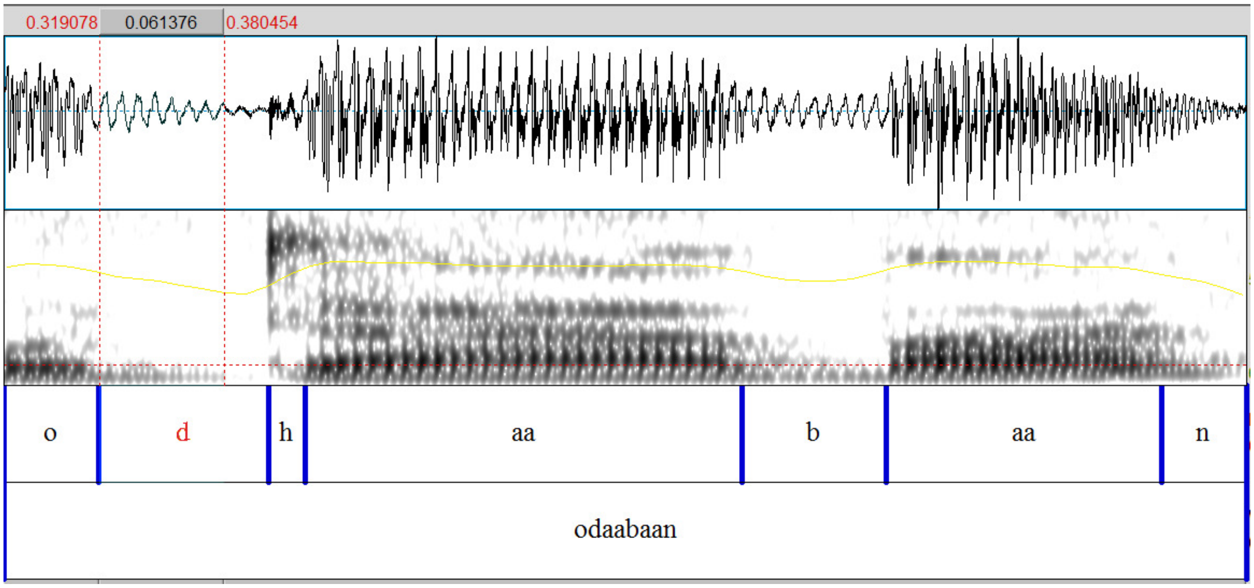


Figure 13. *Spectrogram and waveform for the word odaabaan 'car' produced by Boo (B.0100) from Long Plain.* The voicing for /d/ trails off near the end of the consonant. The duration of the voicing during the closure period is 61 ms.

Other measurements that quantify the physical realization of voicing are its length in proportion to the closure duration and its intensity. In the former case we can measure the length of the voicing portion starting from the onset of the closure. For example in figure 13 the closure duration of /d/ is 84 ms, hence the consonant would be assigned the value 0.73 for voicing duration.[32]

Intensity is measured in decibels. In terms of the lenis-fortis distinction it is practically irrelevant for obstruent consonants, because fortis consonant are generally completely voiceless.[33] A less accurate but quicker way to measure voicing intensity is by measuring the

[32] It is interesting to note, that despite voicing being described as present or not in more contemporary work, Bloomfield actually described them as "partly or wholly voiced" (1956: 8) the most accurate statement in the literature up until now.
[33] Leander (2008) found that in Ozolotepec Zapotec there was no significant difference in terms of intensity between laterals and only a slight difference (2 decibels) between lenis and fortis nasals in word final position, which came out as barely significant (p=.039). For Cypriot Greek lenis and fortis sonorants did show some slight differences but not always in the expected direction (Arvaniti & Tserdanelis 2000).

trough of the intensity contour during the consonant closure and comparing it to the intensity of the flanking vowels.

Measuring the voicing duration and intensity are clearly preferable to the voicing count technique, however they were not used for all speakers in this study. Voicing duration was not recorded for any of the speakers from the Treaty #1 Oral History because these recordings contained low amplitude (but predictable) periodic background noise, which was difficult to distinguish from voicing in cases where the consonant was shorter than approximately 60 ms. While it was easy to tell whether voicing was generally present or not, the background noise introduced an intolerable level of inaccuracy to these measurements, and so there was a concern that interspeaker comparisons would be confounded by differences in signal to noise ratio. The other reason was that low amplitude periodic voicing can be confused with echo from the previous vowel if recordings are not done in a sound proof room. The reason intensity was not recorded was because the different degrees of background noise would make it difficult to compare intensity levels across speakers.

A compromise between the crude method of voicing count and the quantitative measurements of voicing parameters was used in this study. We assigned an ordinal value of voicing from 0 to 5 based on visual observations of the spectrogram and waveform in relation to its flanking vowels (henceforth “Sonority” value). That we had to use this technique is unfortunate since we are potentially losing much rich quantitative data, but it is far superior to the voicing count, in the sense that if there are gross differences in the degree of voicing between speakers and POAs we can get a first approximation. (16) describes the measurement criteria and refers the reader to spectrogram and waveform examples. The levels above 0 are perfectly ordinal when applied to the data and imply increasing levels of periodic energy based on a number of acoustic attributes.

(16) Measurement criteria for the Sonority value.

0: Assigned if the stop has no voicing or the duration of the voicing is less than half of the duration of the closure; ~1…

1: Voicing is present for more than half of the duration of the closure; ~0, ~2…. (figure 14).

2: 1 is true and the intensity of the waveform appears to be half or more the size of its flanking vowels; ~0, 1, ~3… (figure 15).

3: The intensity of voicing appears to be the same as its flanking vowels (the boundaries between stop and vowel are only observable based on spectral discontinuities, such as a change in the shape of the periodic wave instead of its size); ~0, 1, 2, ~4… (figure 16).

4: There is no discernible boundary between the flanking vowels and the stop, but the it can still be heard by the investigator; 3, ~5… (figure 17).

5: Assigned when the stop appears to be completely syncopated, i.e. the researcher cannot see it in the spectrogram nor hear it; ~4.

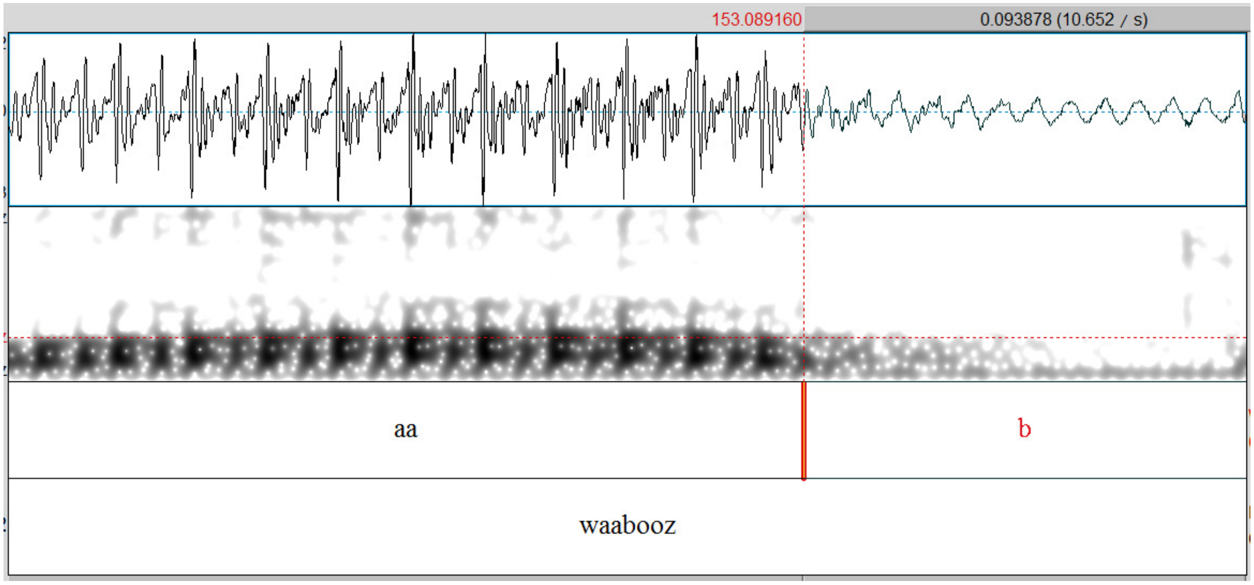


Figure 14. *Spectrogram and waveform of the /aab/ portion of the word waabooz 'rabbit' produced by Boo* (B1to100, 153.1) from Long Plain. The voicing during the /b/ closure is clearly less than half of the preceding vocalic segment: Sonority=1.

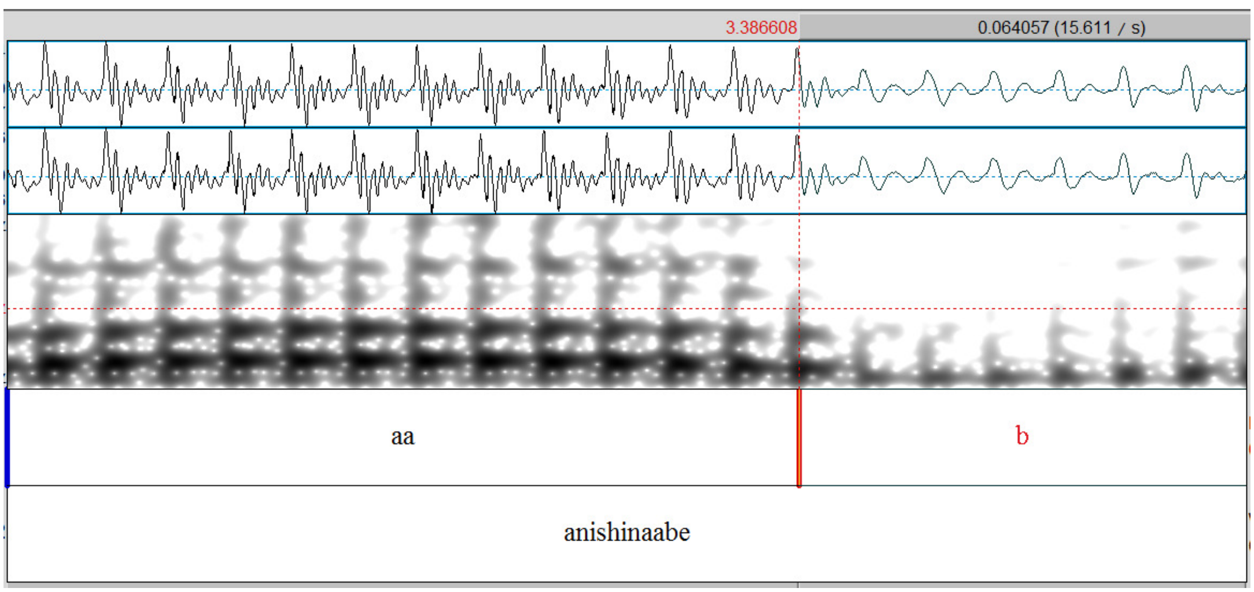


Figure 15. Spectrogram and waveform of the /aab/ portion of the word anishi*naabe 'Indian' produced by SF* (SF.0003) from Brokenhead. The voicing during the /b/ closure is approximately half the size of the preceding vocalic segment: Sonority=2.

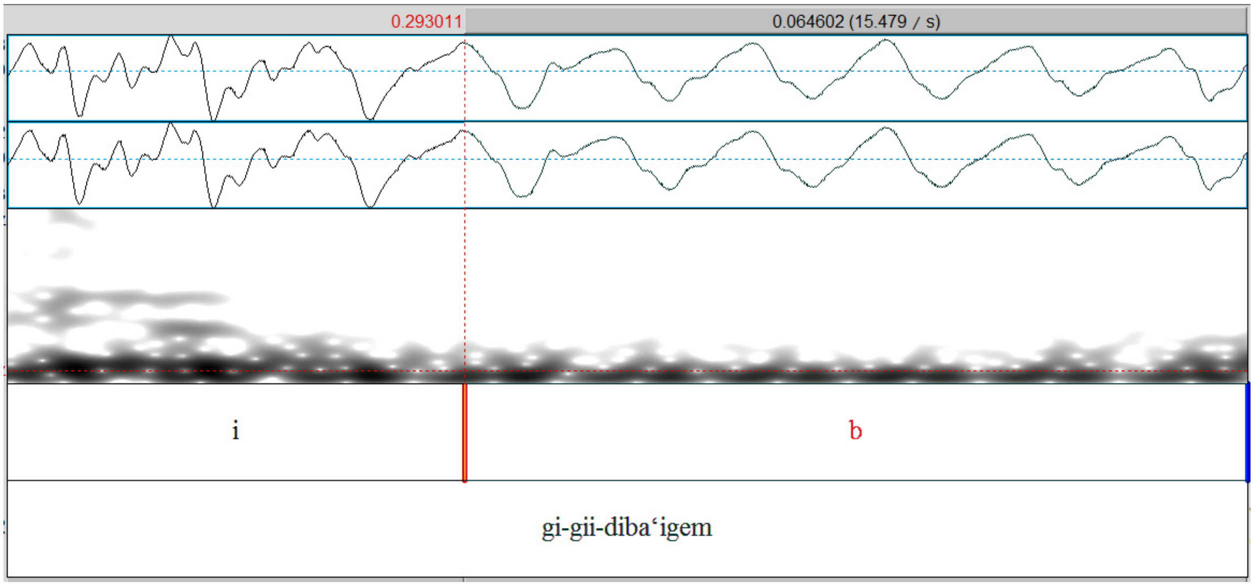


Figure 16. Spectrogram and waveform for the /ib/ portion of gi-gii-*diba`igem ‘You guys* paid *it’ produced by* JB (JB_2_290_900, 635.4) from Sandy Bay. The waveform during the voiced stop is almost as large as the flanking vowel, differing mostly in complexity: Sonority=3.

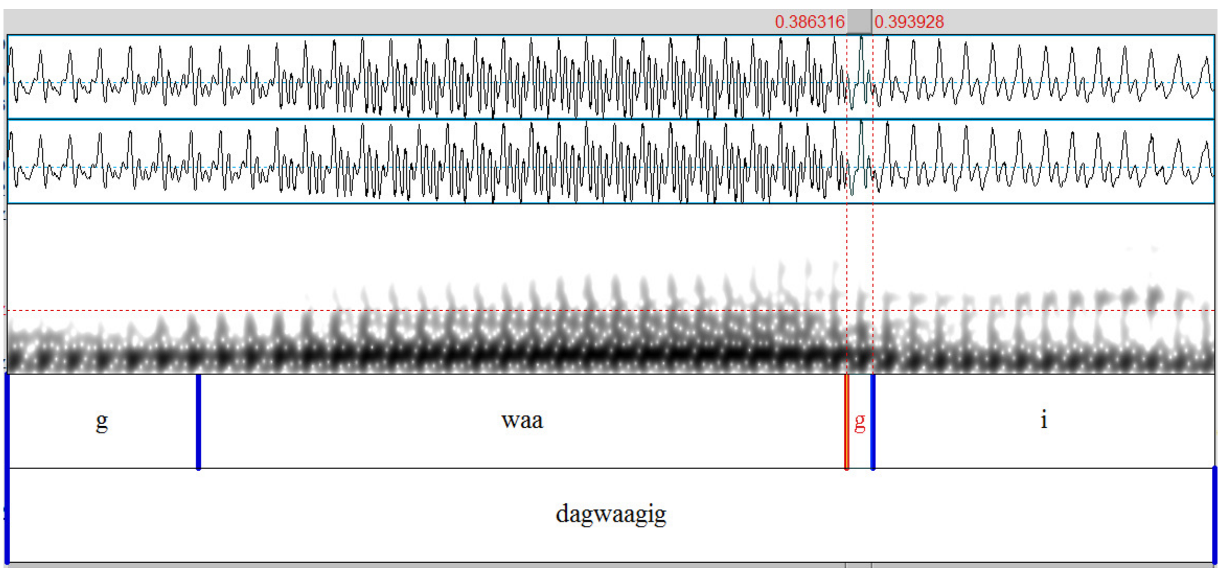


Figure 17. *Spectrogram and waveform for dagwaagig ‘It is autumn’ as produce*d by JB (JB_1_0_300, 194.8) from Sandy Bay. The /g/ is not heard by the present researcher. The consonant duration is recorded as 0 ms: Sonority=5.

These measurements are impressionistic to a greater extent than the measurements that depend on segmentation boundaries. The difference between Sonority value 4 and 5 in particular is completely based on auditory impressions. In these cases the token is assigned a duration value of 0 ms. This was particularly prevalent in the speakers JB, SF and in some cases Boo. A question that needs to be addressed is whether the tokens which are essentially unrecordable in terms of consonant duration should be included in the statistical description. This level of undershoot is ubiquitous for some speakers. The question will be addressed in the section on velars, since only /g/ reaches this level of undershoot.

More precise measurements of voicing were made for a few of the speakers. For Boo, the voicing duration during the closure was recorded as in figure 13. For Boo and NT the voicing intensity during the closure was measured at trough of the intensity curve during the closure against the peak of the intensity curve in the flanking vowels. These data are presented, but because they were only made with one or two speakers they are extremely tentative.

4.3. Probability Models: Description and Technical Problems

Probability models can be used to model the probability of an event occurring given a set of factors (Liao 1994). In this section we explain how we use probability models in this study to quantify the notion of contrast precision described in chapter 3 (4.3.1.). These probability models entail some technical problems with data structures due to their computational complexity. My corpus contains such data structures, and thus brief mention is given to the method adopted to cope with the technical problems (4.3.2.).

4.3.1. Contrast Precision as a Logit Function

Recall in chapter three that we described phonemes as category systems, adopting Pierrehumbert's (2001b, 2003b) terminology. This means that they encode multiple categories, which are density distributions over a particular parameter of a multidimensional phonetic hyperspace. To these categories we can assign a certain value of contrast precision associated with how important a particular dimension is for predicting one phoneme (category system) over another. This will be a function of how much overlap there is between the density distributions on this parameter and how far apart they are. In order to quantify contrast precision as it is defined here we use probability models.

Probability models can assess the likelihood of an event occurring given a set of factors (Liao 1994). Taking instances of lenis or fortis stops as events and their phonetic correlates as factors, we can model the probability of a token stop being fortis as opposed to lenis (fortis= Pr(1), lenis=Pr(0)) given a set of values associated with those phonetic correlates. These models can tell us how important a particular density distribution (inferred from instances of phonetic correlates) is for predicting that a stop is fortis instead of lenis. In other words, we can model contrast precision over a particular dimension for a category of interest.

The particular probability model that we use in this thesis is the loglinear model. This model transforms a normal regression line into an S-shaped curve that represents the change in probability along a particular dimension as the value for that dimension increases. The values of the dimension are modelled as the predictor variable and the probability of fortis (Y=1) over lenis (Y=0) is modelled as the response variable. To take an example from my own data, the density distributions for closure duration for the speaker MR are presented in figure 18 for the bilabial lenis /b/ compared to the bilabial fortis /p/.

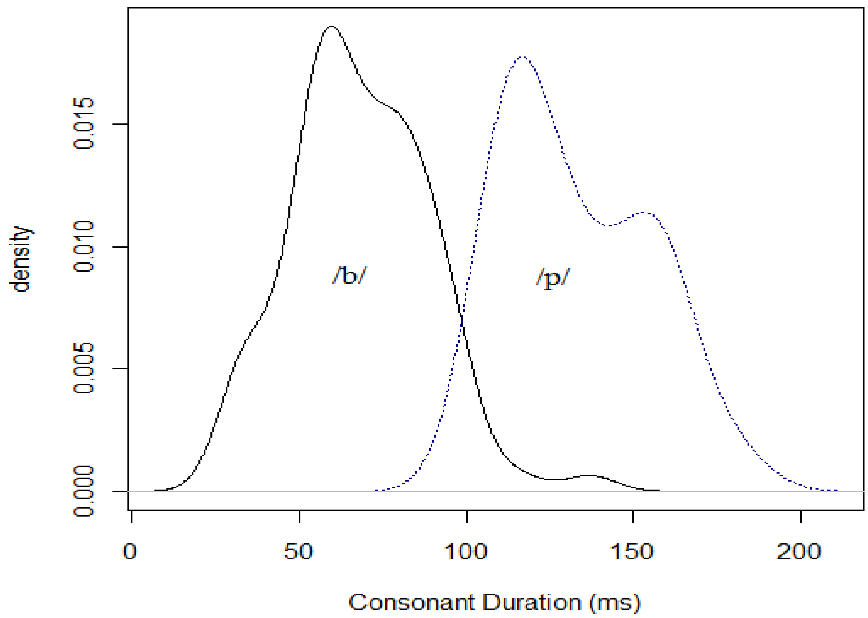


Figure 18. Density distributions for the phonemes /b/ and /p/ on the consonant duration parameter for speaker MR of Fairford.

The loglinear model relates the parameter of consonant duration to the probability that a consonant is /p/ and not /b/ given a particular consonant duration. This is represented in figure 19. The area of cross-over between the two density distributions in the previous figure corresponds to that area where the S-shaped curve is increasing rapidly or has a higher slope (roughly in the range 80-120 ms). The areas of the curve that display a ceiling effect correspond roughly to the areas between the density distributions where there is no overlap (below 80 ms for lenis /b/ and above 120 ms for fortis /p/).[34]

[34] In figure 18 it looks like the highest probability of confusion will be at 100 ms. This is not the case as revealed by the loglinear model in figure 19. The reason for this graphical discrepancy can be attributed to the fact that closure duration is not completely normally distributed.

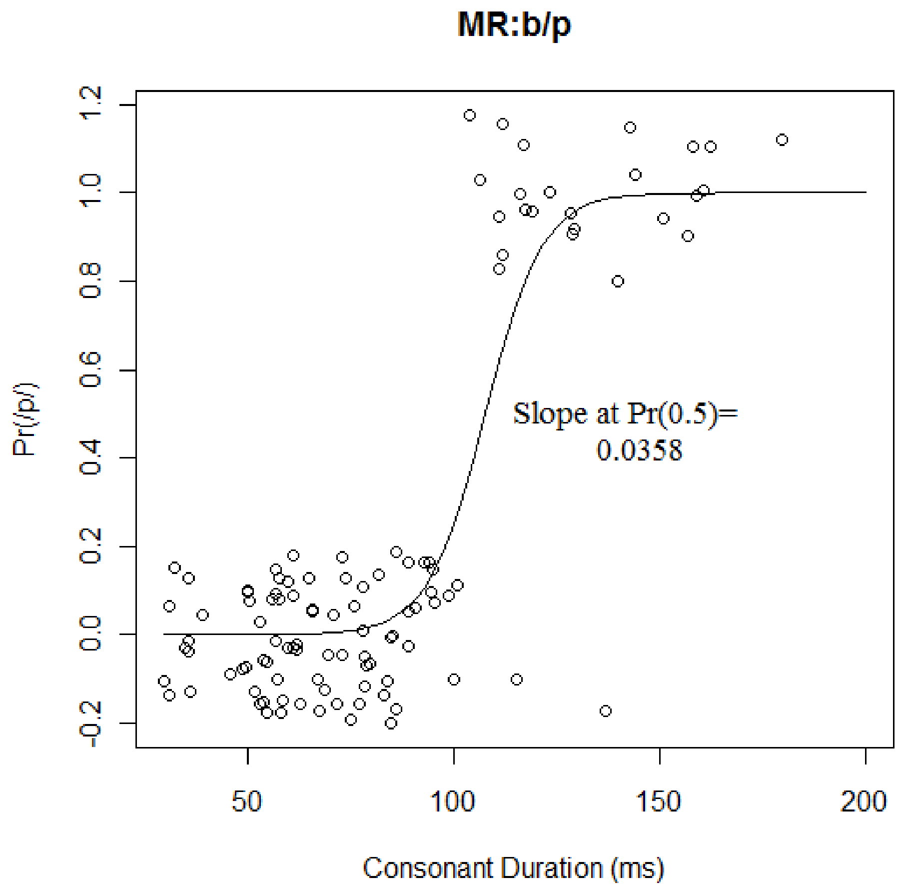


Figure 19. Loglinear curve for the /b/-/p/ contrast on the consonant duration parameter for MR of Fairford. A particular point on the curve represents the probability that a particular bilabial is /p/ and not /b/ given a particular consonant duration.

Before we describe how we can quantify contrast precision we need to first consider the complexities involved in looking at more than one factor at a time in the model described above. When we consider phonemes as multidimensional category systems (instead of their encoding along just one parameter as in figure 18) we are considering how the probability increases in relation to increases or decreases on all of its parameters (instead of one parameter at a time as in figure 19). In this case the predictability of one parameter might be subsumed under its relationship to another. Framing this in terms of perception, a listener may only actually need to pay attention to one or two dimensions at a time to decide whether a stop is fortis or lenis although other cues might be present in the signal (cf. Pothos & Close 2008). With respect to production data this situation is called "multicollinearity". This occurs when two or more predictor variables are correlated with each other with respect to a particular multiple regression model (Baayen 2008). It implies that contrast precision between two category systems is not necessarily an additive function of contrast precision along each of their parameters taken individually.

Although covarying predictors may not play as strong a part in maintaining contrast between two units they are still (by definition and/or theoretical inclination) part of the phonetic encoding of a category system. Let us consider the example of ongoing phonetic change in Korean (cf. Kirby 2011). In Korean the older generation, which relied mostly on VOT to make the distinction between aspirated and lenis stops, was still encoding higher F0 associated with the aspirated set even though in terms of making the relevant contrast it is predictable from VOT. The new generation reversed this relationship. F0 became the primary predictor of the contrast (Kang & Guion 2008). This would not have been possible if the older generation had not been encoding F0 in their aspirated stops.[35] Just because a correlate need not play a part in making a contrast at some point in time does not mean it is not encoded in the category systems of the contrasting elements. This situation implies that there is rarely a simple relationship between contrast precision at a particular dimension in isolation (contrast between categories) and the contrast precision of multiple factors taken at once (contrast between category systems).

One can consider either situation when one quantifies contrast precision. Although, a concern for the latter will help us focus on what is important for speakers making the contrast between lenis

[35] The reason this took place was because longer VOT is associated with higher F0 for physiological reasons (Solé 2007).

and fortis stops synchronically, the former case is important because those redundant parameters have the potential to usurp the position of the main predictors. In this thesis therefore I describe contrast precision along each parameter for the lenis-fortis pairs in isolation, in addition to modelling contrast precision associated with the complex categories of the lenis and fortis stops. The parameters taken in isolation are discussed in the Loglinear I section associated with each of the contrasts grouped by place of articulation (/b/ vs. /p/, /d/ vs. /t/, /g/ vs. /k/). In Loglinear II I discuss the parameters as multiple and potentially interacting factors in a multiple logistic regression model.

To quantify this notion of contrast precision it necessary to give some sort of numerical summary of the loglinear model exemplified in figure 19. There are a number of ways of doing this (Pampel 2001). In the sections on loglinear models we use various measures to summarize different aspects of the relationship defined by loglinear models. These act as different measures of contrast precision. They are defined and justified below. The first three are different types of measures that are based on the predicted probabilities of the loglinear models (using the predict() function in R (cf. Chambers & Hastie 1992)) and the fourth is based on the coefficient associated the predictor variable (cf. Pampel 2001, Gelman & Hill 2007).

R^2: This is a measure of association between the dummy variables (lenis: Y=0, fortis: Y=1) and the predicted probabilities of the logistic regression model. There are various ways of measuring R^2 but the method adopted here is fairly simplistic and specific to our purposes (Lewis-Beck 1980, Berry 1993). Our only interest is that we want to know how close the predicted probabilities for lenis stops are to 0 and how close the fortis stops are to 1. We measure this by taking the mean of the predicted probabilities associated with 0 and the mean of the predicted probabilities associated with 1 and then subtracting the latter from the former. This method thus tells us how close each token of a lenis/fortis stop was to perfect prediction overall.

τ: This is also a measure of association between the dummy variables (lenis: Y=0, fortis: Y=1) and the predicted probabilities of the logistic regression model. Kendall's τ is a rank correlation that measures concordance in relation to discordance (Kendall & Gibbons 1990). The coefficient will be higher the less discordance there is. Rank correlations are often used to summarize logistic regression models (e.g. Baayen 2008). They are advantageous because we do not commit a specification error when using them on data which are not normally distributed, as opposed to R^2 (Lewis-Beck 1980, Berry 1993). They oversimplify the relationship by not telling us how close the predicted probabilities are to perfect prediction (0 in the case of lenis stops, 1 in the case of fortis stops). They are also only concerned with whether the variables increase or decrease together, not where the increase or decrease takes place.

Accuracy: This is a measure of the proportion of lenis/fortis tokens that were classified correctly based on their predicted probabilities in relation to some threshold (cf. van Rijsbergen 1979). In this study we let the threshold be Pr(0.5) corresponding to the highest probability of confusion. If the predicted probability of a lenis falls below 0.5 then it is classified correctly, otherwise not. If the predicted probability of a fortis is above 0.5 then it classified correctly, otherwise not. Then we calculate at the proportion of lenis and fortis tokens classified correctly in relation to the total amount of tokens for each group. Then, we add these two classification percentages together and divide by two. The latter method is used because we do not have equal proportions of lenis to fortis stops for each POA and speaker.

Slope: This is a measure of the slope of the loglinear regression line at the highest probability of confusion for a given predictor. It cannot summarize models with more than one factor but it can give us a good idea of how sharp the category boundary between two density distributions is for a given parameter. It corresponds more directly to how much two density distributions overlap. Although it is interesting to look at when we compare speakers in terms of their contrast precision along a particular parameter, it is difficult to use as a measure of contrast precision for comparing correlates that have different variances and density functions (e.g. skewed as opposed to normally distributed). We use it to describe contrast precision on one dimension at a time (Pampel 2001, Gelman & Hill 2007). It becomes a useful measure of contrast precision when the variables are standardized, otherwise it is difficult to interpret.

Two other statistical terms will be used throughout this thesis. In the second loglinear regression subsection of each main section in the following chapter we use multiple regression models to help us understand contrast as it manifests itself on a multidimensional category system level. The following technical terms will be important for understanding that section.

Interaction: This refers generically to cases where the combined effects of two variables is not a simple sum of their separate effects in a regression model (Dodge 2003). With respect to complex categories this usually implies that two categories are predicting the contrast redundantly to a certain extent. This aspect of complex categories is important because it means that categories that participate in making a contrast do not operate in perfect trading relations with each other all the time, where the absence or loss of the contrast precision of one category implies the increase of another. In the chapters which follow there are some cases, where models for contrasting category systems will include interaction terms to account for multicollinearity between factors (cf. Jaccard 2001).

Akaike Information Criterion (AIC): The AIC is based on the concept of information entropy. Basically it measures the amount of information loss associated with applying a particular model to explain data. This is used to assess the best fitted model for each speaker in the relevant section. Ideally it could be used as a measurement of contrast precision (preferably with other information-theoretic criteria (cf. Anderson 2008)). However we have different sample sizes according to speaker in many cases. Since the AIC is based on information loss this makes it an unreliable measure of contrast precision for comparing speakers. We use it here to select the best model in each speaker for the relevant contrast. The lowest AIC corresponds to the best model. The measurements of contrast precision based on predicted probabilities (R^2, τ, Accuracy described above) are then selected from the best model (cf. Anderson 2008, Burnham & Anderson 2002).

4.3.2. Separation

There is a technical problem associated with applying loglinear models to certain data structures. Separation occurs when the data between two frequency distributions do not overlap. Observe the following the figure 20a and 20b.

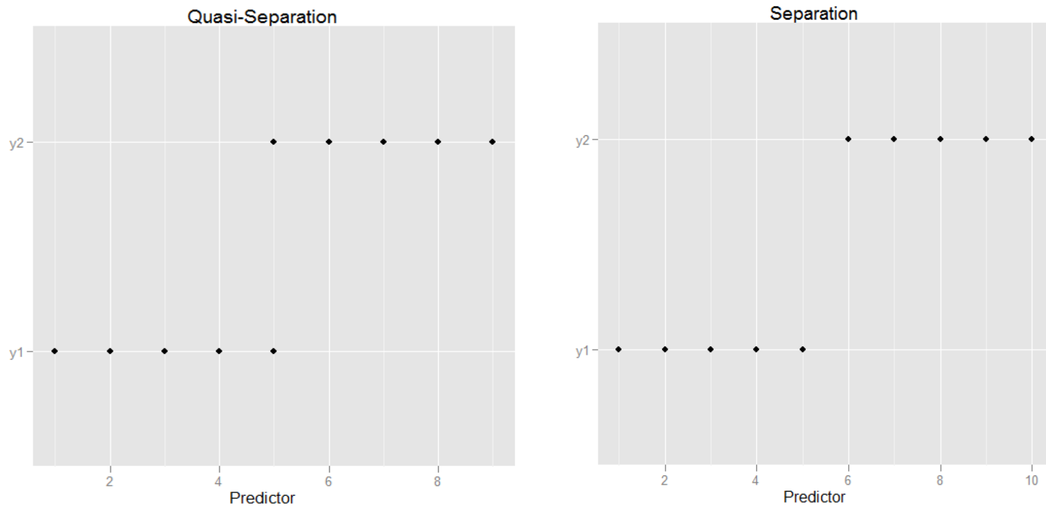


Figure 20a (left). Hypothetical example of quasi-separate data structure. Figure 20b (right). Hypothetical example of completely-separate data structure.

There are two types; Quasi-separation occurs when they overlap on one unit of the predictor variable but do not cross. Complete separation occurs when the frequency distributions do not overlap at all. Quasi-separation and complete separation are exemplified in the diagrams above. In figure 20a the frequency distributions of the variables y1 and y2 are overlapping on one unit. In figure 20b the frequency distributions are completely separated from each other. Both of these situations are problematic for the algorithm that estimates coefficients in logistic regression models. Models that attempt to estimate parameters with data with this type of structure do not converge (Allison 2004, 2008).[36]

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[36] Consider the formula for a loglinear regression below.

$$\ln (P_i / P_i - 1) = \alpha + \beta_1 x_1 + \beta_2 x_2 \ldots\ldots \beta_n x_n$$

The actual values for P_i in this formula are attained through maximum likelihood estimation. For the logistic model an algorithm produces the β coefficients that produce P_i values that maximize the logged likelihood function (lnLF) in the following formula.

$$\ln LF = \sum \; [Y_i * \ln P_i] + [\,(1 - Y_i) * \ln(1 - P_i)] \quad .$$ (Pampel 2001: 43)

The Newton-Raphston algorithm solves the equation by selecting coefficients that make this function the largest (cf. Allison 2004, 2008). The process is repeated until the maximum modification for each parameter estimate from one iteration to the next is smaller than some criterion, considered the convergence point of the algorithm. However, there are certain types of data for which the algorithm does not converge. For instance, if we consider a case where

My data from Saulteaux attest of many examples of quasi-separation. Figure 21 graphs the density distributions for preaspiration of lenis/fortis velars for the speaker WM from Lake St. Martin. The density distribution for the lenis stop is represented by a straight line upwards. Lenis stops never have preaspiration. The density distribution for preaspiration in the fortis stop is represented by a range of values about 40% of which fall on 0 ms. This is an example of quasi-separation. When we compare lenis and fortis stops by preaspiration it occurs in every single case for each speaker.

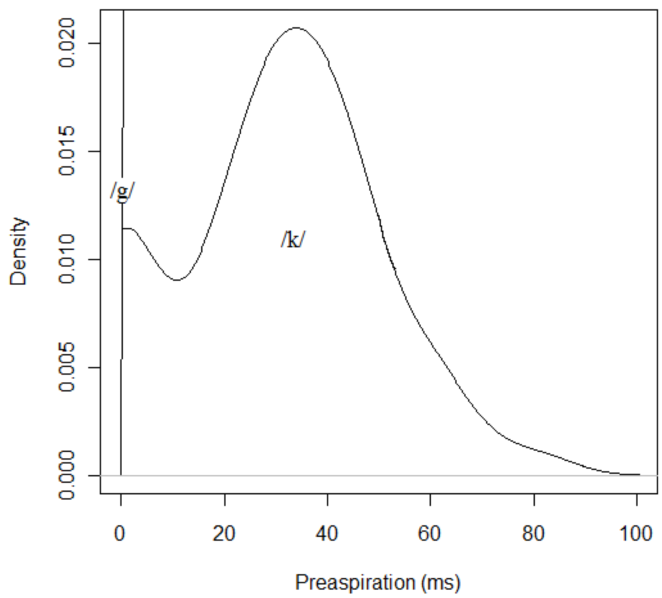

Figure 21. Density distributions for preaspiration in lenis and fortis velars for WM from Lake St. Martin.

In order to deal with this problem I will use the R package brglm(). Bias-reduced generalized linear models are immune to nonconvergence due to separation because the maximum likelihood

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the probability of a particular Y_i for a given X_i is 1 , i.e. if there is some particular threshold of X where we are certain of the value of Y, the equation in above is unsolvable because the logarithm of 0 is undefined. This type of data is called separation. In complete separation "there exists some vector of coefficients **b** such that $y_i = 1$ whenever $\mathbf{bx_i} > 0$ and $y_i = 0$ whenever $\mathbf{bx_i} < 0$. In other words complete separation occurs whenever a linear function of **x** can generate perfect predictions of y."; In quasi-complete separation "there exists some coefficient vector **b** such that $\mathbf{bx_i} \geq 0$ whenever $y_i = 1$ and $\mathbf{bx_i} \leq 0$ whenever $y_i = 0$, and when equality holds for at least one case in each category of the outcome variable" (Allison 2004: 241).

estimation is always reached (Kosmidis 2011, cf. n37 above). It has recently been applied successfully to a number of fields that model data using loglinear or similar models (e.g. Heinze & Schemper 2004). Bias-reduction is used in this study because of the ubiquity of separation in my data (in preaspiration, in the Sonority value, and at times in postaspiration).

5. Phonetic Encoding II: Places of Articulation

This chapter describes the acoustic correlates of lenis and fortis stops taking one place of articulation at a time. From this point on when I say that a particular correlate comes out as (non)significant, I mean specifically that it is (non)significant in a loglinear model where lenis and fortis tokens are modelled as the dummy response variables (lenis: Y=0, fortis: Y=1). The loglinear model subsections for each POA section discuss the different measures of contrast precision described in the previous chapter for each correlate taken individually.

5.1. Bilabials: /b/-/p/

This section describes the acoustic correlates of the lenis-fortis contrast in intervocalic bilabials as represented in the elicitation and corpus data. I assess the effect of each correlate individually. We give the means, standard deviations and proportional differences as measured from the means of the frequency distributions between lenis and fortis stops along each of the parameters: Consonant duration (5.1.1), postaspiration (5.1.2), preaspiration (5.1.3) and voicing (5.1.4). Then we describe the contrast precision measures from our loglinear regression models for each parameter comparing the extent to which these parameters correspond (5.1.5).[37] The second loglinear section discusses the contrast when lenis and fortis stops are viewed as category systems containing all the aforementioned dimensions simultaneously (5.1.6). I choose the best model for each speaker.

One problem needs to be mentioned before we display the results. Fortis bilabials are by far the most infrequent of the stop consonants discussed in this study. This is a problem for models that include more than one factor. The data from NT for example should be looked upon with more scepticism. It is generally recommended that we have ten events per independent variable for logistic regression (e.g. Agresti 2007). This benchmark is not met with NT. Through her whole story there are only 9 tokens of intervocalic fortis /p/ and 30 tokens of /b/ or /p/ in total. The data from SF is also problematic in this regard. There are only 21 tokens of fortis /p/ in 35 minutes of conversation and many of them are from high frequency particles (81 tokens of lenis /b/ were gathered). The conclusions based on the data from NT and SF are much more tentative than the data from other speakers. Multiple regression models are not applied to data from these speakers for bilabials.

[37] One might argue that this discussion is unnecessary because we should only be interested in contrast precision between whole category systems, since these are the real linguistic elements of contrast. We are more generally interested in the contrast between phonemes not a hypothetical contrast between the phonetic dimensions of a phoneme. Dimensions which do not seem to be operative in terms of contrasts between category systems are still part of the phonetic encoding of those category systems, however. In fact, in certain circumstances they form the basis of phonetic change. One dimension where the contrast is encoded redundantly can supersede the main effect eventually and become the primary correlate of the contrast. This is essentially what has been described for Korean (Kirby 2011, cf. chapter 3 of this thesis). Thus, proper description of redundant phonetic encoding is necessary if we are to document processes of phonetic change.

5.1.1. Consonant Duration

Figure 21 displays the closure durations for /b/ and /p/ by speaker. Durations over 230 ms in length were removed. This constituted less than 1% of the tokens (2 out of 917). For some speakers this still leaves a fair amount of outliers. There are a few tokens for lenis /b/ for SF and JB where the consonant duration is 0 ms (consequently assigned a sonority value of 4 or 5). Although consonant lenition does seem to be an aspect of their speech, arguably such extreme instances of hypospeech should be removed. Table (16) displays the means and standard deviations for bilabial stops and the proportional difference between lenis and fortis bilabial stops for all the speakers. In this same table, two values for each of these measures are given for SF and JB. The first includes all of the dropped tokens with 0 ms of duration and the second has these tokens removed. In the loglinear models consonant duration was significant for each speaker ($p<.0001$ for NT, Boo, SF, JB, WM and MR). The range of the difference between lenis and fortis stops is 1:1.5-2.1. WM has the longest bilabial fortis stops overall despite having the smallest difference between lenis and fortis consonants. This might indicate a speech rate difference. The standard deviation for lenis stops is between 19-23 ms, whereas that for fortis stops is between 22-35 ms. Thus /p/ seems to display a wider variation in production than /b/.

(16) Mean, standard deviation and duration ratios for /b/-/p/ contrast by speaker (with 0 ms/without 0 ms).

	Mean		Standard Deviation		Duration Ratios
	b	p	b	p	
NT	81.3	117.9	14.1	14.5	1:1.5
Boo	65.2	119.7	18.9	30.4	1:1.8
SF	60.0/62.3	102.5	20.5/17.1	35.1	1:1.7/1.6
JB	60.1/61.5	130.3	20.0/18.1	33.6	1:2.2/2.1
WM	101.7	140.2	23.1	31.2	1:1.4
MR	67.7	132.9	22.0	21.9	1:1.95

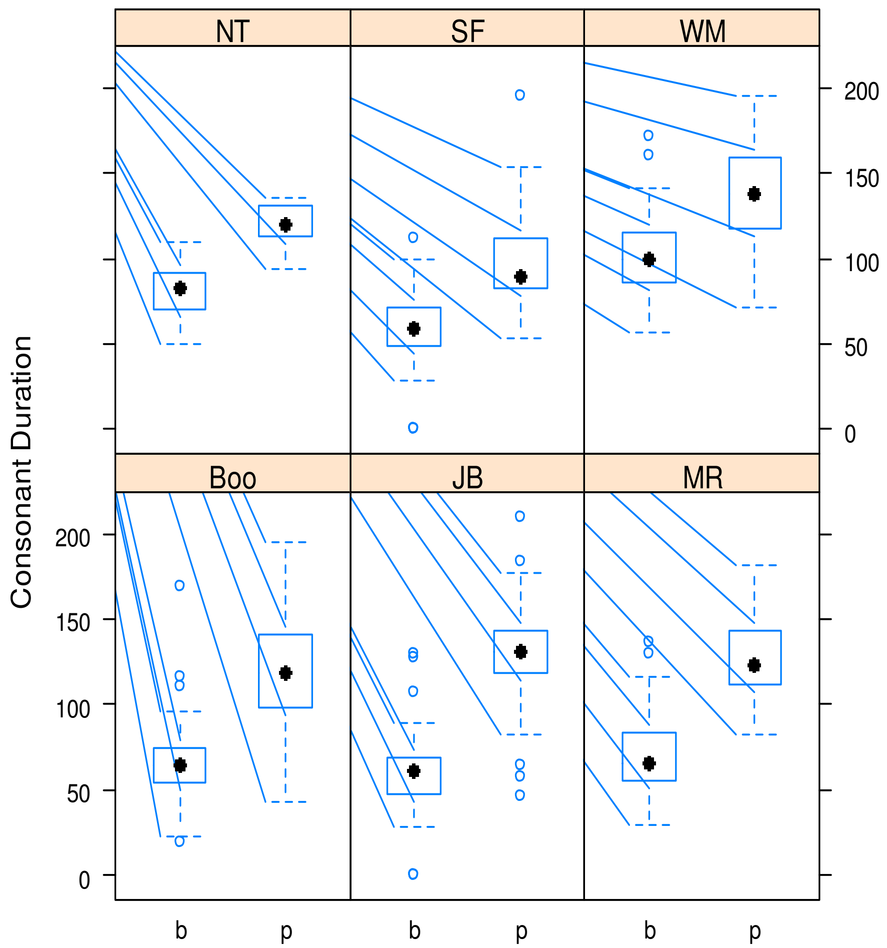


Figure 21. Consonant duration of lenis and fortis bilabials grouped by Speaker.

5.1.2. Postaspiration

Figure 22 displays the differences in postaspiration for each speaker. The very infrequent tokens longer than 90 ms were removed. This was less than 1% of the data for bilabials. For all of the speakers except NT bilabials were postaspirated less than 10% of the time. In the loglinear models postaspiration was a significant predictor of the lenis-fortis contrast in bilabials for Boo ($p<0.0001$), SF ($p<0.0001$), WM ($p=.0019$), JB ($p<0.0001$), MR ($p<0.0011$), but not for NT ($p=0.0647$). Table (17) gives the mean, standard deviations, proportions and duration ratios by speaker. Proportion refers to the proportion of tokens that have any postaspiration at all.

(17) Mean, standard deviations, proportions and duration ratios for the duration of postaspiration for /b/-/p/ by speaker.

	Mean		Standard Deviation		Proportion of postaspirated tokens		Duration Ratios
	b	p	b	p	b	p	b-p
NT	6.7	12.9	6.2	8.4	.6	.89	1.9
Boo	0.95	18.2	3.6	16.8	.09	.63	19.2
SF	1	25.7	4.2	10.4	.06	1	25.7
JB	0	24.3	0	20.8	.01	.74	NA
WM	1	8.3	3.9	13.1	.06	.35	8.3
MR	0.55	5.5	3.1	7.4	.02	.31	9.6

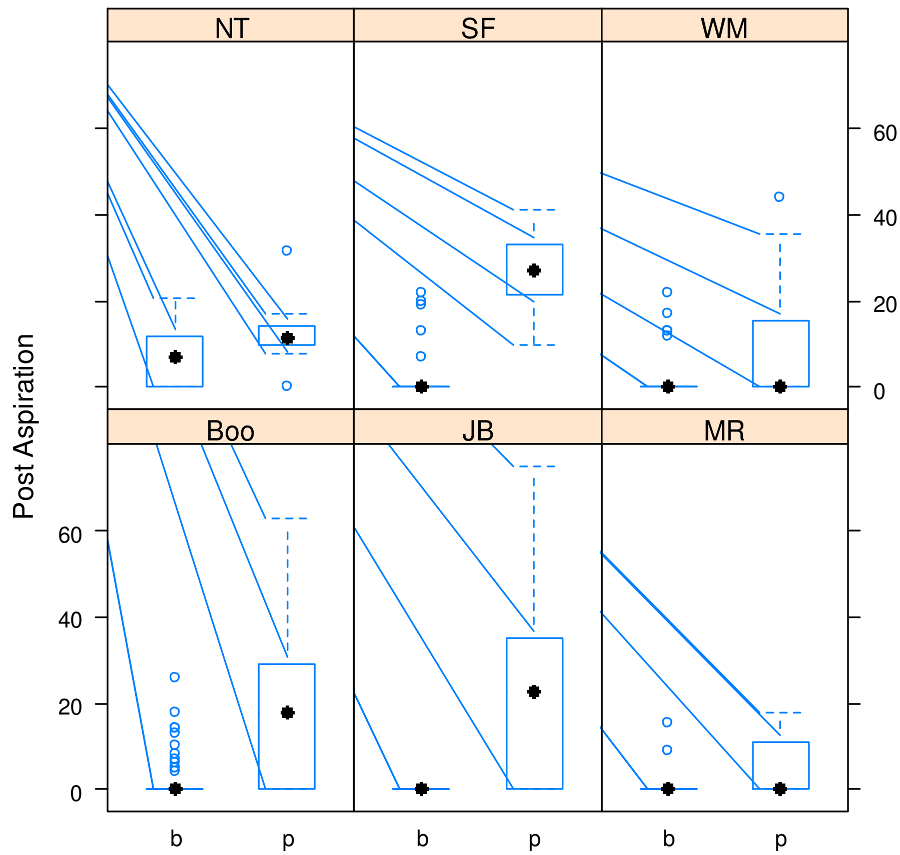


Figure 22. Postaspiration duration by lenis and fortis bilabials grouped by Speaker.

Postaspiration appears to be more important for Boo, JB and SF, than for the other speakers. The consistency with which a speaker uses postaspiration to make the contrast can generally be gleaned from observing a quantile-quantile plot of postaspiration in fortis bilabials (figure 23). The more tokens clustered around 0 ms the speaker has the less important postaspiration is for the speaker. There is quite a bit of variation between speakers in terms of the degree normativity (in Helgason's 2002 sense).

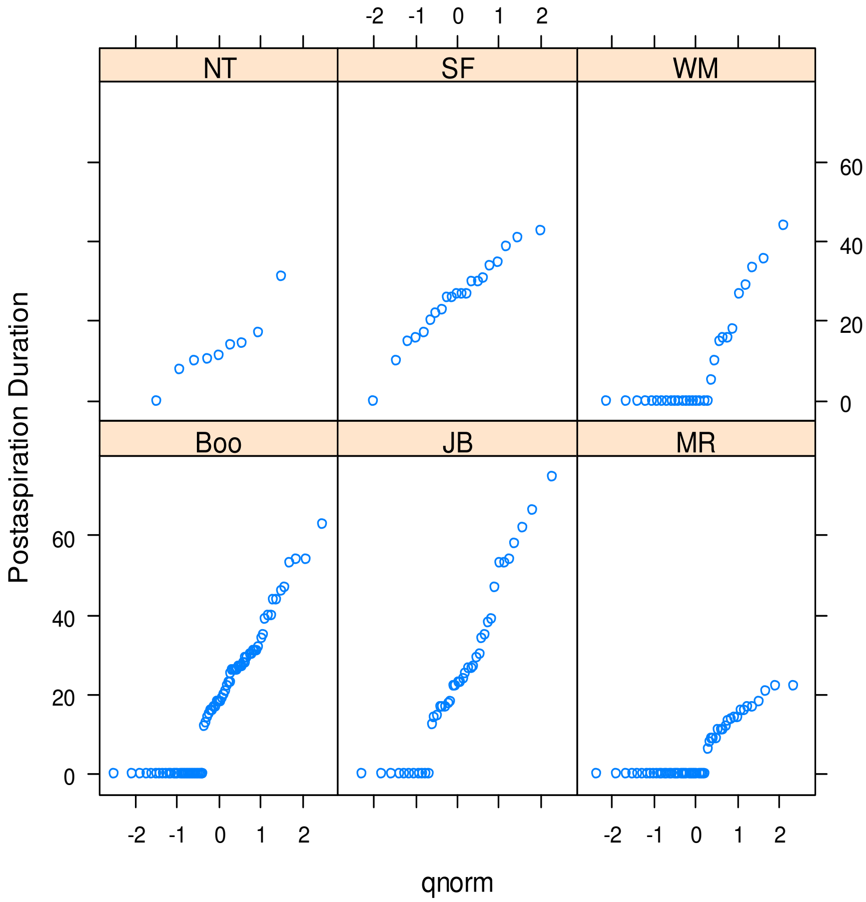


Figure 23. Quantile-quantile plots for postaspiration duration in fortis /p/s grouped by Speaker.

5.1.3. Preaspiration

Preaspiration is a non-normative acoustic correlate for bilabial fortis stops.[38] It does not consistently mark fortis stops and it never occurs with the lenis set. Quantile-quantiles plots for preaspiration duration in /p/s by speaker are given in figure 24. demonstrates that in the majority of cases there is no preaspiration on fortis bilabial stops, but that this varies from speaker to speaker. (18) gives mean, and standard deviation values for preaspiration. It also gives the

[38] A particular correlate is normative where it is marked consistently on a particular phoneme or phoneme class (cf. Helgason 2002). Cross-linguistically preaspiration is often non-normative in this sense. It clearly distinguishes one class from another but is not always present. Itanyuso Trique (Zapotec) is an exception (DiCanio 2008). Some lenis consonants in Itanyuso Trique are preaspirated.

proportion of fortis bilabials that have any preaspiration at all for each speaker. In the logistic regression models only WM came out as significant for preaspiration (p=0.0048). The rest of the speakers' models were not significant.

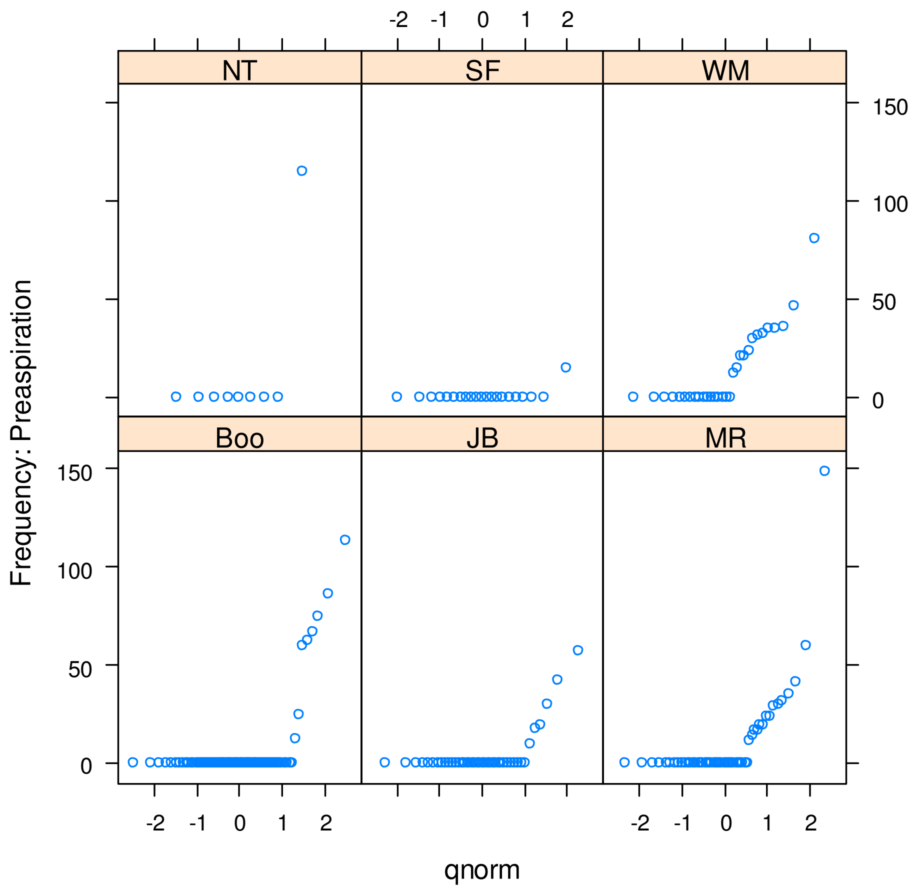


Figure 24. Quantile-quantile plot of preaspiration in fortis bilabials grouped by Speaker.

(18) Mean, standard deviation of preaspiration duration and proportion of preaspirated /p/s by speaker (statistical descriptions under Overall contain all tokens, those under PreAsp contain only token with values above 0 ms).

	Mean		Standard Deviation		Proportion
	Overall	Preasp.	Overall	Preasp.	
NT	12.8	115.1	38.4	NA	0.11
Boo	6.3	62.5	21.2	32.2	0.10
SF	0.7	15.0	3.3	NA	0.05
JB	4.2	29.3	12.1	17.5	0.14
WM	13.95	32.2	19.7	17.5	0.43
MR	9.8	34.7	23.7	34.0	0.28

5.1.4. Voicing

Voicing varies in terms of how much it is employed by each speaker to make the bilabial lenis-fortis contrast. Due to the coarseness of the sonority value measurement used in this study, only very general differences can be observed. In some cases fortis consonants appear to be voiced enough so that they receive sonority value of 1, but upon closer inspection, most of these cases really involved echo from a high intensity previous vowel. Generally fortis consonants are voiceless and all receive a sonority value of 0. We assume, however, that the heavier the voicing in the corresponding lenis, the more the periodic glottal vibrations are providing contrast with the fortis consonant. Figure 25 gives density histograms of lenis /b/ by speaker for the sonority value. Table (19) gives the proportions of values falling within each sonority value.

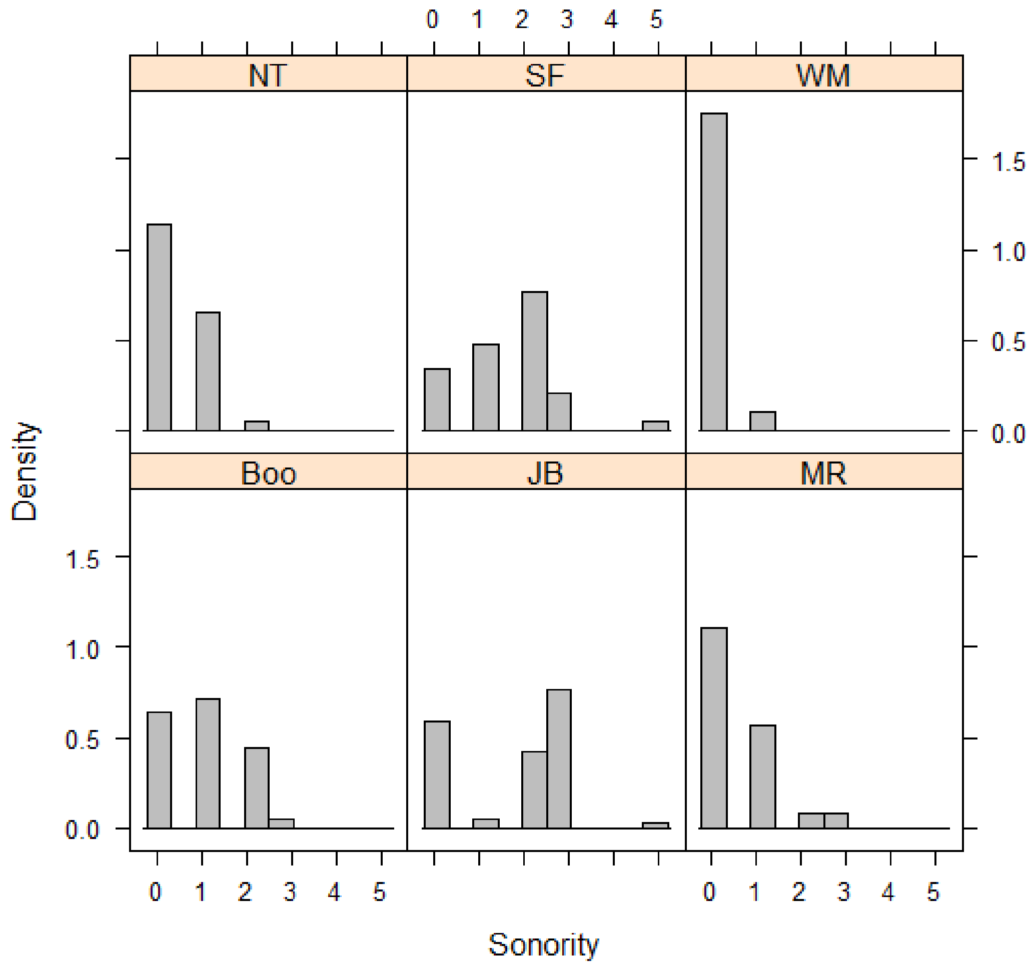


Figure 25. Histograms of the density of sonority values in /b/s by speaker.

In the loglinear models Sonority was significant in Boo (p<0.0001), SF (p=.0007), JB (p=.0011) and MR (p=0.0095). For NT the model was not significant (p=.0586), and for WM the model did not even converge.[39] In WM's speech 92% of the intervocalic /b/s were assigned a sonority value of 0. On the other extreme JB has only 1% of his intervocalic bilabials unvoiced, 60% of them are almost as sonorous as the surrounding vowels.

[39] R gave the following message when the loglinear model was applied to WM's brglm(tense~Sonority...).
Warning message:
In fit.proc(x = X, y = Y, weights = weights, start = start, etastart = etastart, :
Iteration limit reached

(19) Sonority value proportions of /b/ by speaker.

	0	1	2	3	4	5
NT	0.5	0.46	0.04	0	0	0
Boo	0.03	0.57	0.37	0.04	0	0
SF	0.04	0.31	0.48	0.14	0	0.04
JB	0.01	0.04	0.33	**0.60**	0	0.02
WM	**0.92**	0.8	0	0	0	0
MR	0.49	0.40	0.06	0.06	0	0

Notice also that these differences correspond roughly to the consonant duration differences noted in 5.1.1. For example, JB has the greatest difference in voicing and the greatest in consonant duration differences (1:2.1). WM has the least difference in voicing and the least difference in consonant durations (1:1.4). There are physical reasons for expecting this difference, since it is harder to maintain voicing beyond certain closure durations (Ohala 1983).

Values were measured for voicing intensity when there was not a large amount of background noise for NT and Boo. For these speakers the voicing intensity measurements correspond to the sonority value differences. For the voicing intensity ratios Boo had a mean of 0.8533 (sd=0.0522) and NT had a mean of 0.6160 (sd=0.1542) .

5.1.5. Loglinear Models I: Factors

In this section we compare the different measures of contrast precision along each of the phonetic dimensions described above for the contrast between /b/-/p/. We rank the speakers in terms of the importance of each correlate based on these measures of contrast precision seeing to what degree these rankings correspond with the more basic statistical descriptions given above (e.g., proportional difference between means, proportions of preaspirated segments, etc…) and with each other. Where we see noncorrespondences between these different measures we try to explain them based on the statistical structure of the relevant category at each parameter. Although overall the patterns correspond, there is often much discordance between the rankings because the variation between speakers can be fairly subtle. We limit our scope to discussing the speakers with the worst and best models for a given correlate in the particular rankings of contrast precision. When rankings of these speakers do not correspond we attempt to explain why. NT is presented in the charts but should not be taken too seriously because of the small sample size in bilabials for this speaker.

5.1.5.1. Consonant Duration

The measures of contrast precision are given in (20) and the rankings of the speakers in (21).

(20) Measures of contrast precision for /b/ vs. /p/ on consonant duration by speaker.

	Proportional difference	R^2	τ	Slope	Accuracy
NT	1:1.5	.6860	.6062	.0346	.8681
Boo	1:1.8	.6170	.5953	.0209	.7464
SF	1:1.7/1.6	.3967	.4247	.02095	.6877
JB	1:2.2/2.1	.7217	.5929	.0197	.9124
WM	1:1.4	.3580	.4457	.0128	.7260
MR	1:1.95	.8283	.5919	.0357	.9481

(21) Rankings of speakers by measure of contrast precision in (20).

	Ratio from means	R^2	τ	Slope	Accuracy
WORST	**WM**	**WM**	**SF**	**WM**	**SF**
	NT	SF	WM	JB	WM
	SF	Boo	JB	Boo	Boo
	Boo	NT	Boo	SF	NT
	MR	JB	**MR**	NT	JB
BEST	**JB**	**MR**	**NT**	**MR**	**MR**

Closure duration is the worst predictor for WM compared to the other speakers in all measures except for τ coefficient and Accuracy. τ measures discordance against concordance in a ranking of the tokens without consideration for distance between the tokens. Thus, τ descends faster than any other measure as the category distributions overlap more, which accounts for this difference. Thus, we can see that SF is worse than WM because SF has large standard deviations in relation to the mean for the contrasting distributions (by measuring sd/mean for each category). For SF this is .34 for /b/ and /p/ and for WM this ratio is .23 and .22.

Closure duration is the best predictor for MR compared to the other speakers. JB's proportional differences, however, are greater than those for MR. Contrast precision is worse for JB on this parameter because his categories overlap more in relation to their distance.[40] This can be seen by comparing the categories of JB in figure 26a and 26b for the categories of MR on the consonant duration parameter. The ratios of standard deviation to mean are .33 and .26 for JB and .32 and .16 for MR. This difference corresponds to JBs lower slope compared to the other speakers in

[40] In fact from the density distributions in figures 26a and 26b it looks as if JB's category encoded with /p/ on the closure duration parameter might have multimodal structure. This implies that there may be hard interactions with other factors in JBs complex category.

general (ranking second). The probability that a particular stop token gets recognized as fortis based on closure duration rises by 3.5% for every 1 ms of difference at the highest probability of confusion. For JB it rises slower near the overlapping distributions, at 1% per 1 ms.

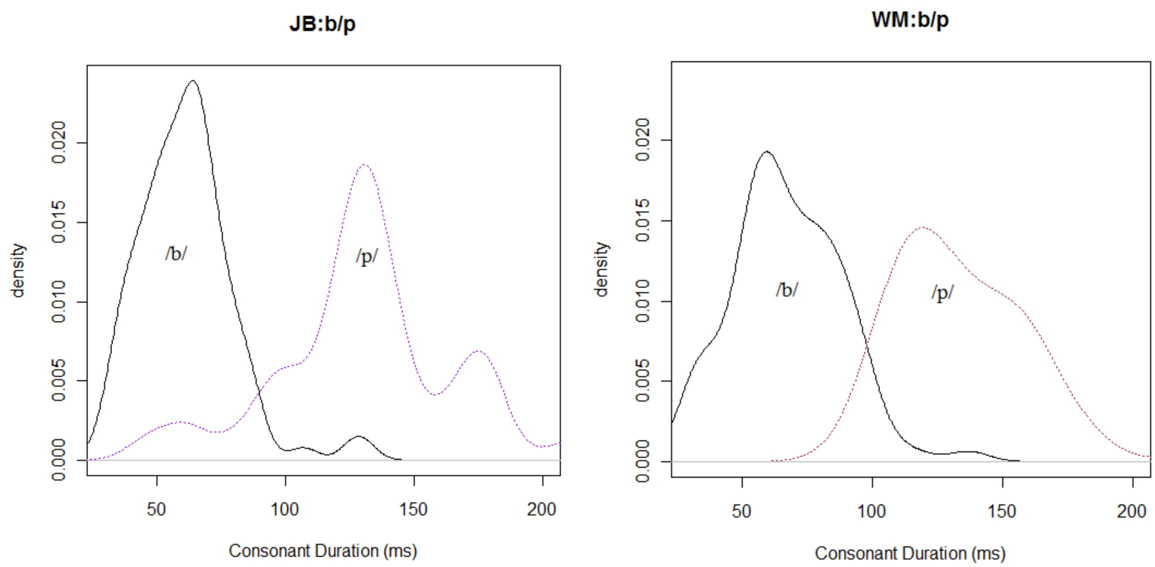


Figure 26a (left). Categories for /b/ and /p/ on consonant duration for WM. Figure 26b (right). Categories for /b/ and /p/ on consonant duration for WM.

5.1.5.2. Postaspiration

The measures of contrast precision are given in (22) and the rankings of the speakers by measurement in (23). The difference in proportions is measured by taking the proportion of postaspirated fortis tokens minus the proportion of postaspirated lenis tokens.

(22) Measures of contrast precision for /b/ vs./p/ on postaspiration by speaker.

	Difference in proportions	R^2	τ	Slope	Accuracy
NT	.29	.141	.317	.0292	.5347
Boo	.54	.413	.573	.0395	.7966
SF	.94	.763	.827	.0664	.9210

JB	.73	.631	.748	.0701	.8637
WM	.29	.144	.369	.0256	.6195
MR	.29	.168	.414	.0522	.6481

(23) Rankings of speakers by measure of contrast precision in (22).

	Difference of proportions	R^2	τ	Slope	Accuracy
WORST	**NT, WM, MR**	**NT**	**NT**	**WM**	**NT**
		WM	**WM**	**NT**	**WM**
		MR	MR	Boo	MR
	Boo	Boo	Boo	MR	Boo
	JB	JB	JB	SF	JB
BEST	**SF**	**SF**	**SF**	**JB**	**SF**

Postaspiration appears to be the worst predictor for NT and WM compared to the other speakers. WM has a larger standard deviation for postaspirated fortis /p/s than NT, which accounts for why WM is ranked even lower with regards to slope (NT: sd=8.4 ms, WM: sd=13.1 ms). Postaspiration is the best predictor of the contrast for SF except with regards to the slope. At the highest probability of confusion (Pr(0.5)) the probability that a particular stop token is fortis /p/ is increasing 0.3% faster for JB than for SF. This corresponds to a difference in the sharpness of their category boundaries. Despite the fact that SF seems to have better contrast precision overall, JB has a sharper category boundary. The difference is graphed in figure 27a and figure 27b. JB's slope is slightly sharper than SF's but since JB has more fortis stops with 0 ms of postaspiration (figure 27a) his model is worse overall.

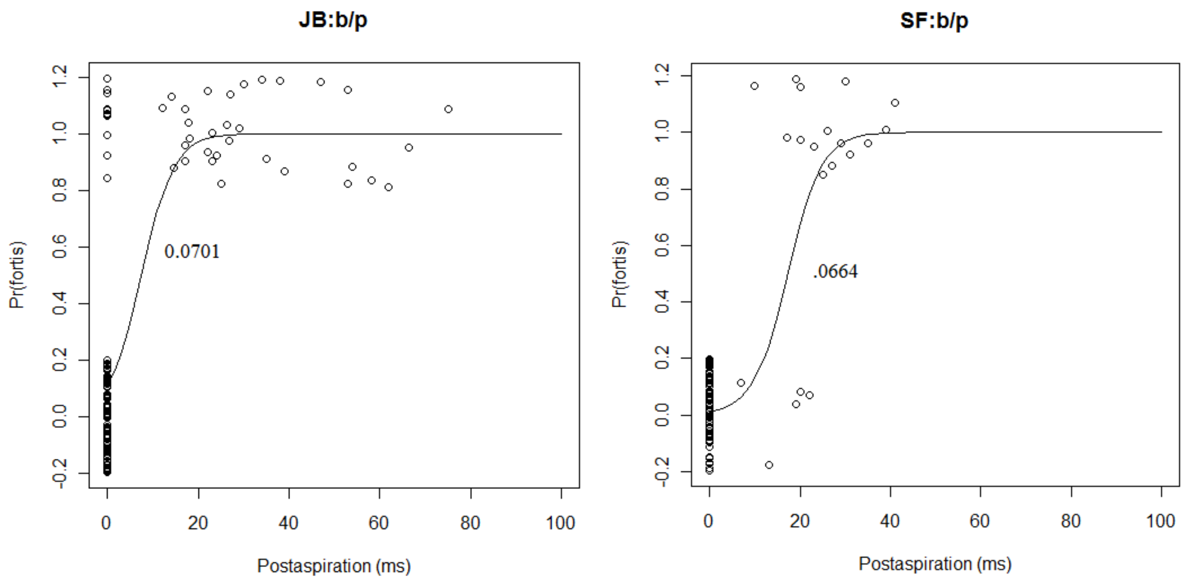


Figure 27a (left). Loglinear curve for Pr(/p/) on postaspiration for JB. Figure 27b (right . Loglinear curve for Pr(/p/) on postaspiration for SF.

5.1.5.3. Preaspiration

The measures of contrast precision are given in (24) and the rankings of speaker by measure in (25). Proportion in the following table refers to the proportion of preaspirated fortis stops. Lenis stops never have preaspiration.

(24) Measures of contrast precision for /b/ vs. /p/ on preaspiration by speaker.

	Proportion	R^2	τ	Slope	Accuracy
NT	.11	.051	.1334	.0045	.5556
Boo	.10	.053	.2539	.0143	.5380
SF	.05	.030	.1452	.0377	.5333
JB	.14	.074	.2673	.0297	.5714
WM	.43	.297	.5280	.0431	.7097
MR	.28	.091	.2899	.0310	.5800

(25) Rankings of speakers by measure of contrast precision in (24).

	Proportions	R^2	τ	Slope	Accuracy
WORST	**SF**	**SF**	NT	NT	SF
	Boo	NT	**SF**	**Boo**	**NT**
	NT	Boo	Boo	**JB**	**Boo**
	JB	JB	JB	SF	JB
	MR	MR	MR	MR	MR
BEST	**WM**	**WM**	**WM**	**WM**	**WM**

Preaspiration is the least powerful correlate for SF out of all the speakers based on the proportion of preaspirated fortis stops, the R^2 and Accuracy.[41] SF is ranked higher for the slope because even though he only has one preaspirated fortis /p/ it is much closer to 0 ms than for the other speakers (The lenis stop's preaspiration category has a mean of 0 ms with a standard deviation of 0 ms). SF's one preaspirated fortis /p/ has a duration on 15 ms. Boo has a mean duration of 62.5 ms associated with his preaspirated stops and JB has 29 ms. SF has a sharper slope than Boo and JB but only because the space in millisecond units of preaspiration for the category to ceiling to the 15 ms token is shorter. These discrepancies in the rankings reveal that in many cases the slope measurement emphasizes category boundary sharpness as opposed to how important a predictor might be for making contrast per se especially when the variables are not normalized across speakers. For this particular instance the measures of association (R^2 and τ) seem to be more appropriate measures of contrast precision.

[41] The reader will notice that there is also discordance between NT and SF for the τ. This has more to do with how the τ punished ties rather than how it describes the statistical structure of the data. SF and NT only have one case of a preaspirated fortis /p/. The τ tells us that the correlation is better for SF than NT only because SF has a larger amount of ties in proportion to discordance than SF (Kendall & Gibbons 1990).

5.1.5.4. Sonority

(26) gives the measures of contrast precision for the sonority value. (27) gives the rankings of the speakers by measurement. WM does not have R^2, a slope or Accuracy measurement because the loglinear model for this speaker did not converge. Proportion in the following table refers to the proportion of lenis /b/s that have a Sonority value above 0. Intuitively the higher this value is the better the correlate should be for the speaker.

(26) Measures of contrast precision for /b/ vs. /p/ on sonority by speaker.

	Proportion	R^2	τ	Slope	Accuracy
NT	.5	.2155	.4738	.73215	.5000
Boo	.97	.8660	.7885	1.5203	.9711
SF	.96	.7664	.5851	1.3110	.9877
JB	.99	.9491	.7981	1.3480	.9946
WM	.08	__	.1538	__	.5000
MR	.51	.1917	.4221	.9405	.5000

(27) Rankings of speakers by measure of contrast precision in (26).

	Proportions	R^2	τ	Slope	Accuracy
WORST	**NT**	**MR**	**MR**	**NT**	**NT, MR,**
	MR	**NT**	**NT**	**MR**	**WM**
	SF	SF	SF	SF	Boo
	Boo	**Boo**	**Boo**	**JB**	**SF**
BEST	**JB**	**JB**	**JB**	**Boo**	**JB**

NT and MR trade off in their rankings according to measure of contrast precision. NT has a sharper slope because she has a higher percentage of her voiced lenis stops values with a Sonority of 1 than MR (Sonority for NT=1: .46, Sonority for MR=1: .4) although MR has a slightly lower percentage of voiceless lenis stops. The same explanation applies to the discordance between Boo and JB. JB has a shallower slope than Boo because Boo has more voiced lenis stops with a sonority value of 1 (.57) or 2 (.37), whereas for JB a higher proportion are clustered at a sonority value of 2 (.33) and 3 (.60). Compare the histograms between these two speakers in figure 28a. This translates into the differences in slope graphed in the loglinear curves in figure 28b. The loglinear model for JB is represented by a solid line, that for Boo by the dotted line.

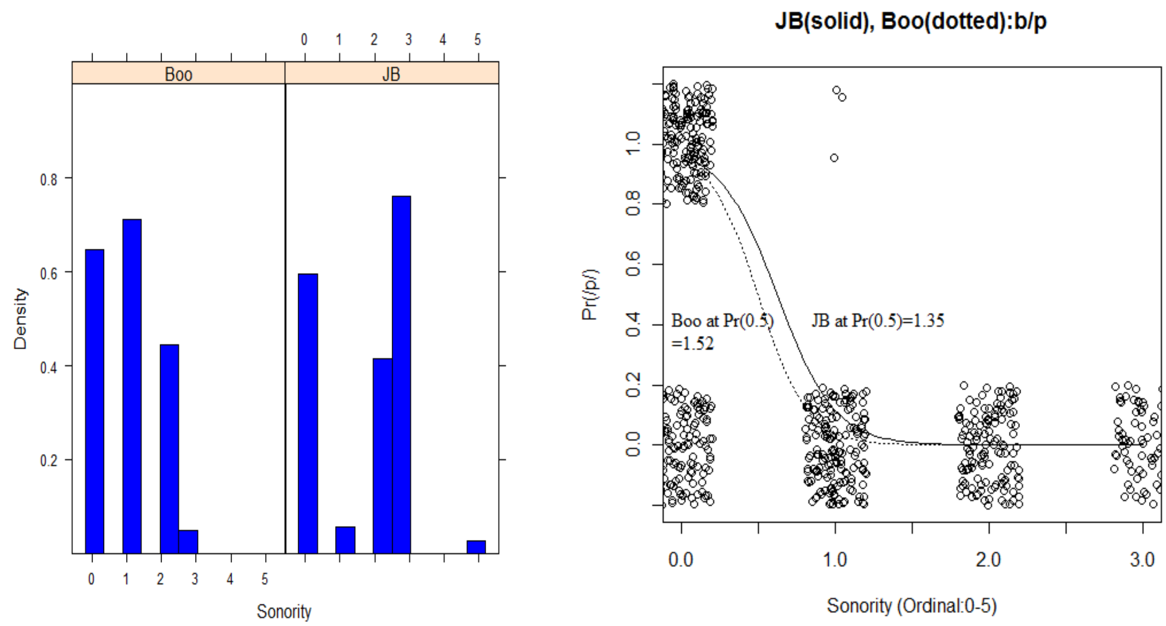


Figure 28a (left) Histograms for /b/s according to sonority values for Boo (left) and JB (right). Figure 28b. Loglinear curves for /b/ vs. /p/ on sonority for Boo (dotted) and JB (solid).

5.1.6. Loglinear Models II: Multiple Regression

In this section I use multiple regression to assess the main hypothesis stated in chapter 3, that contrasts between lenis-fortis sets as category systems have close to the same degree of contrast precision. I try to fit the best model for each speaker using the AIC (Burnham & Anderson 2002, Anderson 2008). In each section I start with what I will call **the basic model** which consists of an additive multiple logistic regression models with all of the factors discussed in the previous section.[42] Based on the results of the basic model, nonsignificant factors are removed and suspected interactions are added until **the best model** is achieved (determined by the lowest AIC).[43] I then compare the models for all the speakers. We discuss the different degrees of contrast precision according to measurement for each speaker.

Only the /b/-/p/ contrast in Boo, JB, WM and MR are modelled in this section because there are so few tokens for SF and NT. The amount of tokens for each speaker for bilabials is presented in (28).

(28)	Boo	JB	MR	NT	SF	WM
p	81	42	26	9	15	31
b	153	94	85	25	82	79

5.1.6.1. Boo Bumble: /b/-/p/

Results for the basic model are presented in (29). The AIC for this model is 55.5.

(29) Basic model for Boo: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	-2.119	0.255
ConsDur	0.0469	0.016 *

[42] Gelman & Hill (2007: 69) give some general principles for model building. The methodology employed here, where the best model is deduced from the basic model follows their first principle: "Include all input variables that, for substantive reasons, might be expected to be important in predicting the outcome." As reviewed in the methodology section all the factors meet this criterion, since they have all shown to be contrastive between lenis-fortis pairs cross-linguistically (cf. DiCanio 2008).

[43] Adding "suspected" interactions also follows the general principles of model building laid out in Gelman & Hill (2007: 69). Interactions will be suspected where we might expect nonorthogonalities in marking contrasts due to nonorthogonalities in the mapping of articulation to acoustic output. For instance, since it is harder to maintain voicing beyond a certain closure duration, it could be reasonable to have an interaction term between voicing and consonant duration.

PostAsp	0.0095	0.776	
PreAsp	-0.0087	0.664	
Sonority	-4.5279	1.63e-07	***

When postaspiration and preaspiration were removed the AIC decreased to 50.92. In the multiplicative model with these two correlates the interaction between consonant duration and sonority was significant (p<.0001) but Sonority was not (p=.0965) and the AIC increased to 51.67. We, therefore, tentatively give Boo the model with only consonant duration and sonority, the results for which are presented in (30) with no interaction term.

(30) Best model for Boo: /b/-/p/

	Estimate	Pr(>|z|)	
(Intercept)	-2.091	0.2777	
ConsDur	0.0497	0.0140	*
Sonority	-4.770	3.38e-09	***

5.1.6.2. Joseph Beaulieu: /b/-/p/

Results for the basic model are presented in (31). The AIC for the basic model is 21.83.

(31) Best model for JB: /b/-/p/

	Estimate	Pr(>|z|)	
(Intercept)	-0.173	0.9511	
ConsDur	0.0189	0.3811	
PostAsp	0.0317	0.3762	
PreAsp	-0.0194	0.6351	
Sonority	-3.1126	0.0133	*

Only sonority is left when all nonsignificant factors are removed. The AIC for this model fell to 14.72. When an interaction term between consonant duration and sonority was added, the term was significant (p=.0074), but the AIC rose to 17.72. Hence the results for JB's best model are given in (32).

(32) Best model for JB: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	3.303	5.64e-05 ***
Sonority	-5.354	0.0010 **

5.1.6.3. Willy Marsden: /b/-/p/

The results of the basic model for WM are given in (33). The AIC is 66.61.

(33) Basic model for WM: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	-8.253	1.12e-05 ***
ConsDur	0.0553	0.0002 ***
PostAsp	0.1367	0.0103 *
PreAsp	0.1864	0.1080
Sonority	-1.0337	0.5609

When nonsignificant factors were removed the AIC rose to 75.84. When I readded preaspiration to the model the AIC decreased to 64.38, below the AIC of the basic model, although preaspiration was not significant.[44] This results of this final model are given in (34).

(34) Best model for WM: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	-8.3188	1.12e-05 ***
ConsDur	0.0549	0.0002 ***
PreAsp	0.2131	0.1083

[44] Following Gelman & Hill (2007) we include nonsignificant terms, if they make sense within our model.

PostAsp	0.1433	0.0079 **

Another model which makes sense and is only slightly worse in terms of the AIC is one with an interaction term between consonant duration and postaspiration and only consonant duration and preaspiration terms as main effects.[45] The AIC for this model is 64.47. It is given below.

(35) Alternative model for WM: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	-8.0301	1.39e-05 ***
ConsDur	0.0528	0.0003 ***
PreAsp	0.1770	0.0823 .
ConsDur:PostAsp	0.0014	0.0198 *

5.1.6.4. Mary Ryle: /b/-/p/

The basic model for MR is presented in (36). The AIC of this model is 35.01.

(36) Basic model for MR: /b/-/p/

	Estimate	Pr(>|z|)
(Intercept)	-13.3811	0.0001 ***
ConsDur	0.1205	0.0002 ***
PostAsp	0.1157	0.3747
PreAsp	-0.0032	0.9661
Sonority	0.9644	0.4395

[45] ConsDur:PostAsp is not technically an interaction term, it is really a data manipulation of consonant duration based on postaspiration since postaspiration is not a main effect. Whether this term is theoretically motivated or not is unclear to me at this point.

When nonsignificant factors were removed the AIC decreased to 29.38. No significant two way interactions were found with consonant duration and any other potential predictor. The results of the best model which contains only consonant duration are given in (37).

(37) Best model for MR:/b/-/p/

	Estimate	Pr(>|z|)	
(Intercept)	-15.3547	4.40e-05	***
ConsDur	0.1425	6.49e-05	***

5.1.6.4. Overview: /b/-/p/ as Complex Categories

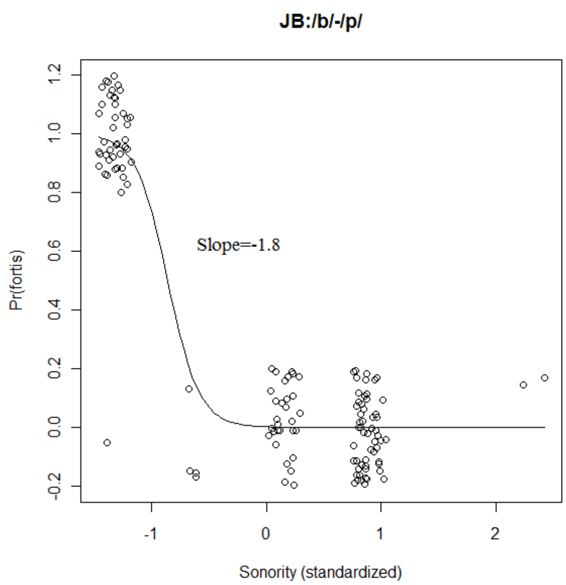
In this section we compare the speakers in terms of the contrast between their complex categories. In the previous section we chose the best model for each speaker. None of the speakers had the exact same model. This is summarized in (38).

(38) Overview of the best models for the /b/-/p/ contrast with standardized coefficients by speaker.

	ConsDur	PostAsp	PreAsp	Sonority
Boo	1.730			-3.974
JB				-7.234
WM	1.808	1.182	2.555	
MR	5.310			

Note that in many cases a correlate is omitted from a particular speaker's model even though when it is isolated it is significant and appears strong. A good example is consonant duration for JB where the proportional difference between lenis-fortis stops was the greatest (1:2.1). Despite this consonant duration is essentially predictable from sonority and thus not enough is added to the model by including it as a factor (without the risk of over fitting). However, it is still phonetically encoded in the complex categories, as evidenced by the fact that there is a large difference between /b/ and /p/ at that parameter. For MR the relationship appears to be opposite, although voicing for her does not appear to display the same potential as consonant duration does for JB (cf. 5.1.5.4.). Figures 29a and 29b give the loglinear curves for JB and MR respectively in relation to their most important correlate.

For Boo the situation is different. His model implies that consonant duration and sonority trade off with each other enough such that both dimensions could be seen as important for maintaining the contrast. The difference between MR, JB and Boo can be described with reference to the following graphs.



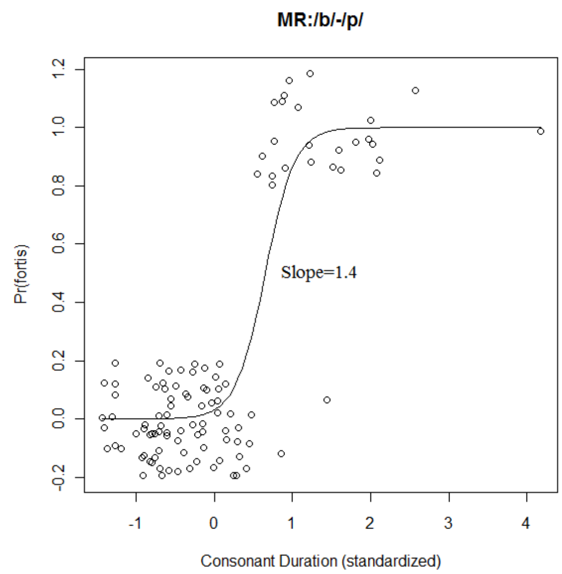
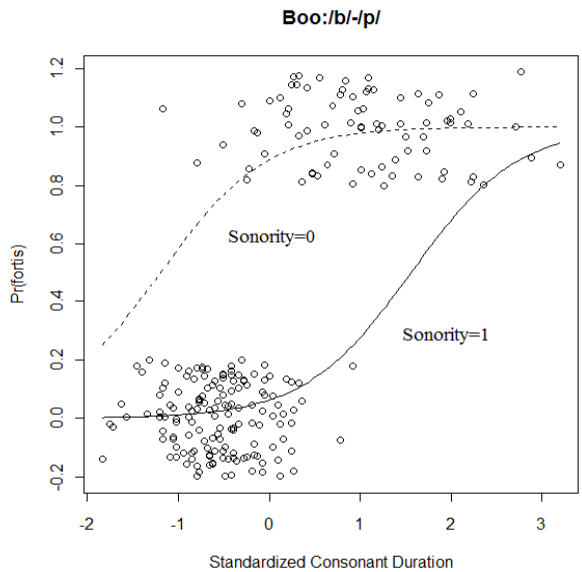


Figure 29a. Loglinear curve for Pr(/p/) in JB's best model. Figure 29b. Loglinear curve for Pr(/p/) in MR's best model.

Figures 30a gives the loglinear curves for consonant duration at different values of sonority (the 25% (solid) and 50% (dotted) quartiles). This graph demonstrates that the loglinear curve rises much more sharply when the sonority value is 1 rather than when it is voiced. Figure 30b gives the loglinear curves for the sonority value with different levels of consonant duration (at the 25% (dotted) and 75% (solid) quartile). These graphs demonstrate that in Boo's /b/-/p/ model as the importance of one correlate increases the other decreases, and vice versa. To a certain extent these correlates operate in a kind of trading relation with each other in production. That said, they are not completely orthogonal. The model which was constructed that contained an interaction term between the two correlates demonstrated that these two correlates do interact, however, indicating that the predictors are not completely additive. The interaction term was not large enough compared to the main effects, however, for us to use in this study according to the information-theoretic criterion that we adhere to. Even if consonant duration and voicing trade off to a certain degree it would be odd to find a case where they were totally nonorthogonal unless they were in radically different phonological positions (cf. Pierrehumbert 2000a, 2000b)[46]. Increases in glottal vibrations during the closure should tend to correlate with a decrease in consonant duration as vocal fold vibration becomes more difficult beyond certain closure durations (Ohala 1983).

[46] We might also expect that consonant duration and voicing would be more orthogonal in languages described as using voicing [+/- voice] and consonant duration [+/-long] distinctively such as Arabic which has a singleton-geminate contrast in addition to a voicing contrast.



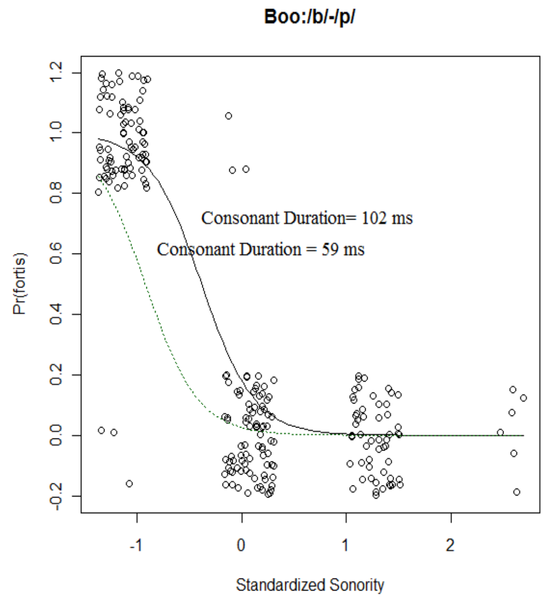


Figure 30a. Loglinear curves for Pr(/p/) on consonant duration with Sonority at 1 (solid) and 0 (dotted) for Boo.
Figure 30b. Loglinear curves for Pr(/p/) on sonority with consonant duration at 59 (dotted) and 102 (solid) for Boo.

The following tables compare the measures of contrast precision between the parameters taken in isolation and the best model by speaker. Accuracy measurements for contrast precision by speaker are given in (39). The column with Best is the contrast between category systems irrespective of the amount and type of dimension involved.

(39) Accuracy for /b/-/p/ contrast by speaker (rows) and dimensional or multidimensional space (columns).

	ConsDur	PostAsp	PreAsp	Sonority	Best
Boo	.7464	.7966	.5380	.9711	.9744
JB	.9124	.8637	.5714	.9946	.9946
WM	.7260	.6195	.7097	.5000	.8098
MR	.9481	.6481	.5800	.5000	.9481
Range	.72-.94	.53-.86	.56-.71	.50-.99	.81-.99

A theme in much of the literature on phonetic typology is that languages cut up the parametric phonetic space in different ways in the formation of language specific phonological categories (cf. Pierrehumbert 2003b). The differential importance of phonetic correlates by speaker indicates that we may have found this type of pattern within the production of the Saulteaux spoken in Manitoba as well. At this point we cannot assess the sociolinguistic variables that might be involved because each of the speakers are from different communities. However, all Ojibwe speakers (we assume) have approximately the same phonological inventories (the same oppositions are made between lenis and fortis stops). Based on this we might assume that they all have the same functional drive to maintain the lenis-fortis contrast. It is therefore reasonable to assume that they have approximately the same degrees of contrast precision between phonemes when they are described as category systems the differential use of phonetic correlates notwithstanding. As can be seen from (39) to a certain extent we have corroborated this thesis even based only on the four correlates I investigated in this study. The range of variation seems to be greater between the contrast precisions of speakers at individual parameters than it is between the /b/-/p/ phonemes as category systems and the speakers vary according to the weight of each correlate and or whether they use a particular correlate at all to mark a contrast. However, WM has a much lower Accuracy measurement than the other speakers for his best model. It may be the case that in fact the lenis-fortis contrast is less robust for WM, but there are a number of possible correlates that were not investigated in this study that could also be participating in the /b/-/p/ contrast for WM. Dozens of additional correlates have been noted to covary with the lenis-fortis contrast cross-linguistically; F0 or F0 flexion (e.g. Löfqvist et al. 1989, Kingston et al. 2008; cf. Abramson 2003 for Pattani-Malay and Muller 2001 for Chukese), F1 or F2 flexion (cf. Debrock 1977 for Dutch and French, Moreton 2004 for English, Leander 2008 for Ozolotepec Zapotec), breathy-stiff phonation in flanking vowels[47] (cf. Cho &

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[47] For Seoul Korean and Cheju, Cho and Ladefoged (2001) found that so-called lenis stops were more breathy than fortis stops. For Standard German, Jessen (1998) found the opposite trend for what are considered "lenis" and

Ladefoged 2000 for Seoul Korean and Cheju and Jessen 1998 for Standard German), among others (cf. Lisker 1986).

Despite these problems, the statistical summaries of the /b/-/p/ contrast across speakers indicate that correlates in production are being used with different weights attached to them by speaker. Whether this implies that the contrast between /b/ and /p/ as category systems has the same degree of contrast precision between speakers awaits further research (e.g. investigation of more correlates). We also need some way of deciding whether in fact we should expect the same level of contrast precision to exist for each speaker and what factors might condition these potential differences (e.g. relative position on hypo-hyperspeech continuum, functional load associated with the relevant phonemic opposition, interactions between sociolinguistc variables, etc…) .[48] Until such issues are addressed and integrated into our framework it is difficult to come up with clear answers to the more complex questions about the structure of system-wide phonemic oppositions (such as the lenis-fortis distinction) in relation to phonetic variation, within a speaker, between speakers and between dialects.

"fortis" (or "lax" and "tense" if the reader wishes) in the literature on German phonetics. The direction in which the correlate covaries is irrelevant, however. If we find that correlates tend to covary in the same direction cross-linguistically it can be related to nonorthogonal mappings between articulation and acoustic output (cf. Pierrehumbert 2000 on this point on the acoustic correlate to vowel distinctions). Longer voiceless laryngeal gestures will in general produce longer postaspiration because greater intraoral pressure will cause a more intense noise burst after the release (Stevens 2000). Shorter closure durations will tend to be correlated with more and stronger vocal fold vibrations because it is difficult to maintain voicing beyond a certain closure duration (Ohala 1983)

[48] Perhaps certain speakers expect that their interlocutor is relying on more top-down processing than others (cf. McClelland & Elman 1986). In this situation we would expect that contrast precision would diminish as a function of the hypo-hyper speech continuum (Moon Lindblom 1994). Perhaps the lenis-fortis contrast bears differential degrees of functional load (cf. Hockett 1967) depending on which speakers are involved in the linguistic exchange. The higher the functional load the higher we would expect the overall contrast precision to be.

5.2. Dentals/Alveolars: /d/-/t/

This section describes the acoustic correlates of the lenis-fortis contrast in intervocalic dental/alveolar stops as represented in my elicitation and corpus data. We assess the effect of each correlate individually. We give the means, standard deviation and proportional differences as measured from the means of the frequency distributions between lenis and fortis stops along each of the parameters: Consonant duration (5.2.1), postaspiration (5.2.2), preaspiration (5.2.3) and voicing (5.2.4). Then we describe the contrast precision measures from our loglinear regression models for each parameter comparing the extent to which these measures correspond (5.2.5). The second loglinear section discusses the contrast when lenis and fortis stops are viewed as category systems containing any or all of the afore mentioned dimensions simultaneously (5.2.6). Unlike for bilabials, lenis and fortis dental/alveolar stops are well attested in all the speakers. The speaker for which there were the fewest tokens was NT who had 29 fortis /t/s.

5.2.1. Consonant Duration

Figure 31 displays the closure durations for each speaker for dental/alveolar stops. (40) displays the mean, standard deviations and proportions for each speaker for consonant duration. Outliers were identified as tokens that were longer than 250 ms and removed. There were only three of these (less than 1% of the tokens). In the loglinear models closure duration came out as significant for five of the speakers (Boo: $p<0.0001$, SF: p= $p<0.0001$, JB: p= $p<0.0001$, WM: $p<0.0001$, MR: $p<0.0001$, NT: $p=0.0161$). Notice that the importance of this correlate by speaker for dental/alveolars corresponds roughly to that for bilabials in terms of the rankings. JB is the highest for both followed by either Boo or MR. SF and WM are the lowest (not counting NT). The rankings are roughly the same but the proportional differences between lenis and fortis stops are not as great. For bilabials fortis stops were between 1.5-2.2 the length of lenis stops. For alveolars/dentals the difference is between 1.2-1.7. Thus, this correlate appears to be fairly POA contingent.

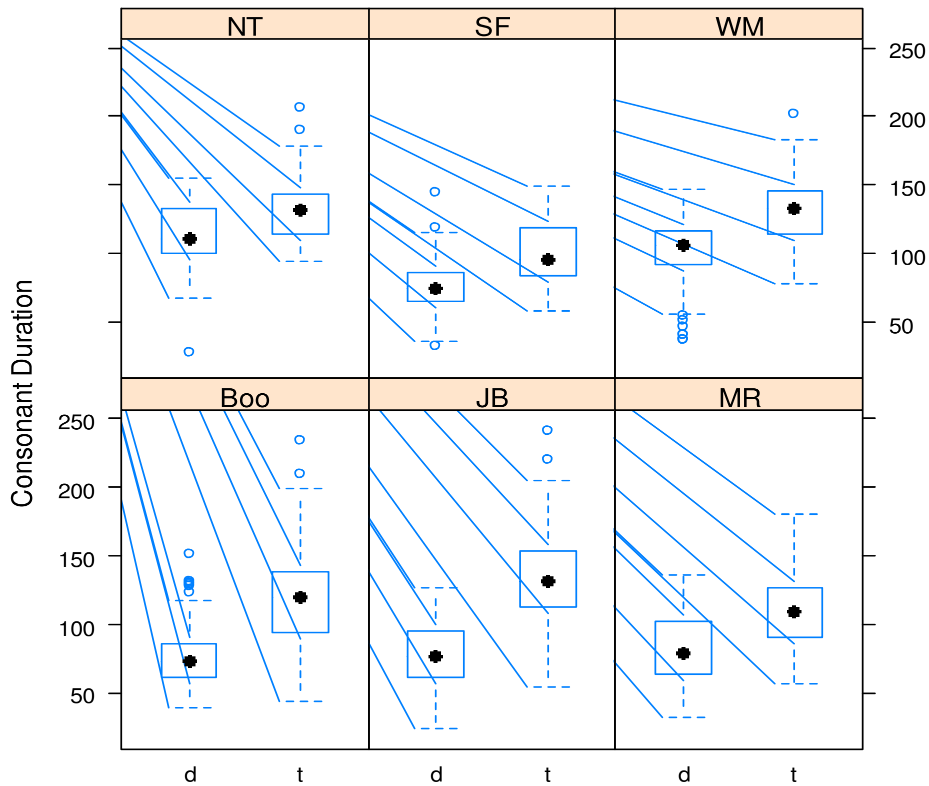


Figure 31. Consonant duration of /d/ vs./t/ by speaker.

(40) Mean, standard deviation and duration ratios for /d/ vs. /t/ on consonant duration by speaker.

	Mean		Standard Deviation		Duration Ratios
	d	t	d	t	
NT	112.8	135.2	25.5	28.3	**1:1.2**
Boo	77.0	121.7	21.0	37.7	1:1.6
SF	75.6	98.9	18.9	24.0	1:1.3

JB	76.6	132.0	23.4	37.4	**1:1.7**
WM	101.0	132.2	26.8	25.5	1:1.3
MR	80.7	109.5	24.9	24.0	1:1.4

5.2.2. Postaspiration

Figure 32 displays the postaspiration differences by Speaker. (41) gives the mean, standard deviations, proportions and durational ratios for /d/ and /t/. Outliers above 60 ms were removed. This was less than 1% of the data (1/773). The standard deviations for lenis consonants remained large nevertheless.

Although the postaspiration of fortis consonants are all higher in terms of duration and overall amount of postaspirated segments than those for lenis stops, the difference is slight. The logistic regression model with postaspiration was significant Boo ($p<0.0001$), SF ($p=0.0017$) and MR ($p=0.0214$). Postaspiration was a nonsignificant predictor of the contrast for NT ($p=0.457$) and JB ($p=0.1467$). The model did not converge for WM.

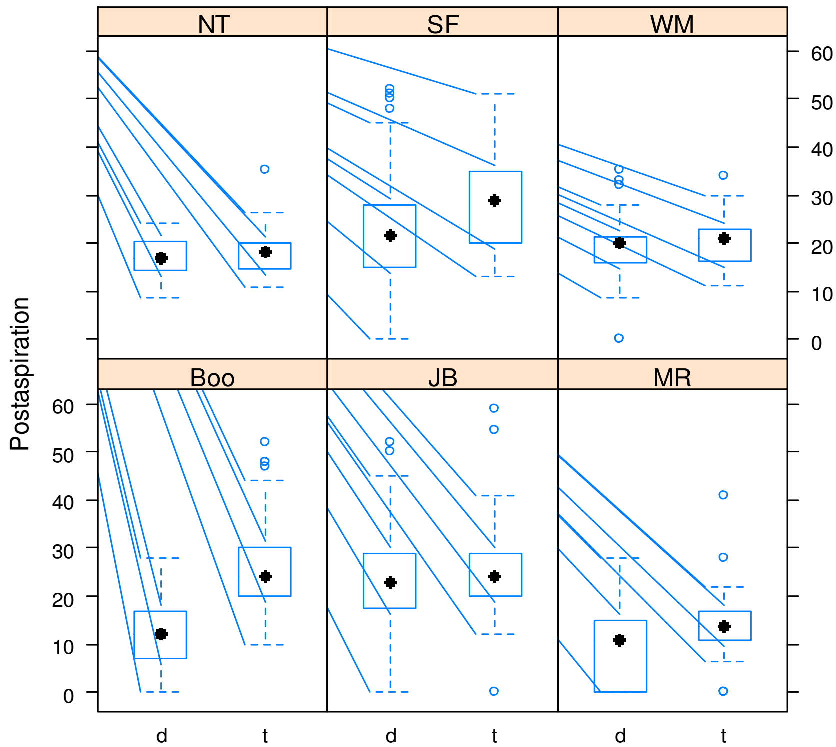


Figure 32. Postaspiration duration (ms) of /d/ vs. /t/ by speaker.

(41) Mean, standard deviation, proportions and duration ratios for postaspiration of /d/ vs. /t/ by speaker. Proportion refers to the proportion of tokens (lenis or fortis) which have any postaspiration at all).

	Mean		Standard Deviation		Proportions		Duration ratios d:t
	d	t	d	t	d	t	
NT	16.9	18.0	3.9	5.2	1	1	1:1.1
Boo	11.4	26.3	7.7	9.5	.78	1	1:2.3
SF	21.9	30.0	14.0	10.2	.86	1	1:1.4
JB	21.9	24.8	23.4	37.4	.88	.98	1:1.1
WM	17.7	20.2	6.7	4.5	.95	1	1:1.1
MR	10.3	13.7	7.6	6.6	.73	.94	1:1.3

As noted before lenis /d/ is peculiar in that it typically has some postaspiration in intervocalic position. This is not the case with bilabials, nor with velars. There does not seem to be a description of lenis /d/s in Ojibwe as having breathy voiced aspiration in the literature, however. Relative duration of postaspiration does not seem to be contrastive for the dental/alveolar lenis-fortis stops (except for NT and JB).

Despite the fact that postaspiration seems to be a weak predictor because lenis /d/ often has a substantial amount of postaspiration associated with it, there may be other acoustic differences between the postaspiration in /d/ and /t/ that are not strictly durational. Although this question could not be addressed in this thesis it appears that the postaspiration of the /t/s has more high frequency frication associated with it, whereas with /d/, the duration reflects VOT lag whether breathy or not. This topic requires future research, if this correlate is contrastive it surely goes against the grain of feature economy. Long postaspiration might be contrastive for bilabials and velars but for dental/alveolars the contrast might be between aspiration and breathy voice aspiration a phonetic feature usually reserved for languages with more than just a two way contrast between stops at a particular POA such as Hindi (e.g. Dixit 1987).

5.2.3. Preaspiration

Preaspiration is a non-normative correlate of the lenis-fortis contrast in dental/alveolar stops. It does not occur with every fortis token (some /t/'s have 0 ms preaspiration). Lenis /d/s never have preaspiration, and thus the data structure is quasi-separate. The quantile-quantile plots in figure 33 give an idea of the differences in preaspiration between speakers. These display fortis stops so that the reader can get an idea of how many of the fortis stops surface with or without preaspiration. All tokens were left in. (42) gives the mean, standard deviations and proportions associated with preaspirated stops. In the former case we give the mean and standard deviations with and without 0 ms tokens. Overall in (42) refers to a data set where all the 0 ms tokens are left in whereas Preasp. refers to the mean and standard deviations of preaspiration where 0 ms tokens are removed. In the loglinear models preaspiration was a significant predictor for every speaker (NT: p=0.0317, Boo: p<0.0001, SF: p=0.0208, JB: p=0.0065, WM: p=0.0041, MR: p=0.0049).

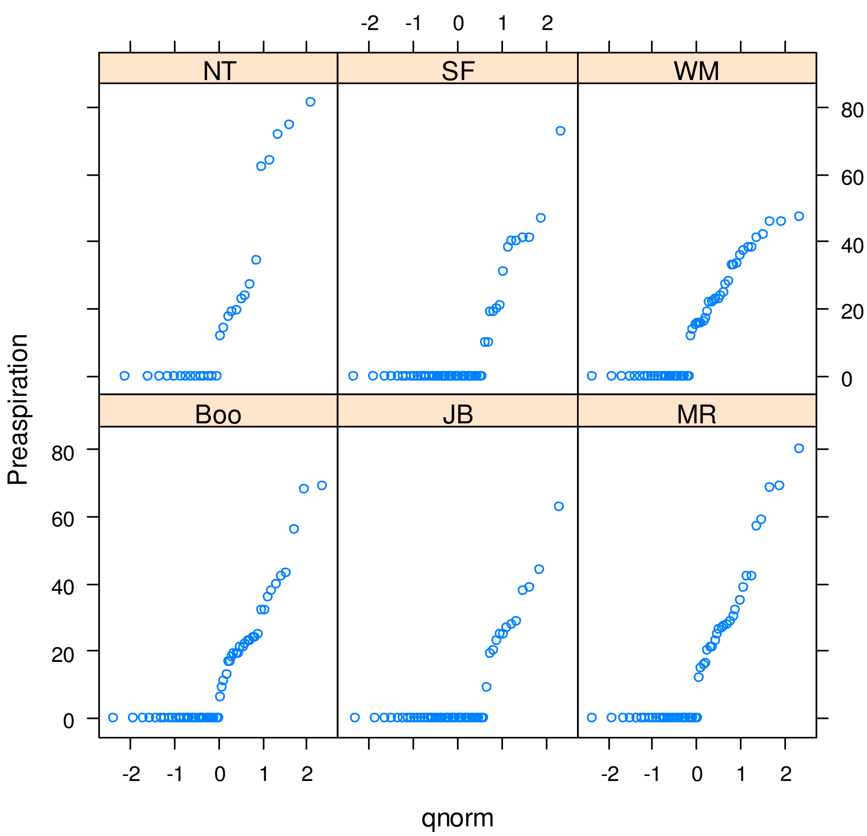


Figure 41. Quantile-quantile plot of preaspiration in fortis alveolar stops by Speaker

(42) Mean, standard deviation, and proportions for /d/ vs. /t/ on preaspiration by speaker. (Statistical descriptions under the column Overall contain all fortis tokens, those under the column PreAsp. contain only fortis tokens with preaspiration above 0 ms.)

Mean	Standard Deviation	Proportion

	Overall	Preasp.	Overall	Preasp.	
NT	19.7	38.9	26.2	25.7	0.50
Boo	13.8	28.1	18.2	16.1	0.49
SF	8.8	32.1	16.9	17.1	0.27
JB	7.8	29.9	14.9	13.6	0.26
WM	15.3	27.6	16.0	10.8	0.56
MR	16.6	34.4	21.6	18.6	0.48

We might attribute some of the variance associated with preaspiration to other sources. Ojibwe has a distinction between short and long vowels. In the literature a distinction is sometimes made between vowels that devoice before fortis consonants in certain circumstances and preaspiration associated with the fortis consonants (e.g. Valentine 1994). No such distinction has been made in this study, and it is difficult to see how it could be done in principle. Preaspiration may, in certain circumstances, be a form of previous vowel reduction. The literature has often noted that only short vowels undergo this reduction and that long vowels are always stressed (e.g. Piggott 1980, Valentine 2001, Swierzbin 2003). In figure 34 it looks as if preaspiration is much more prevalent for fortis stops which follow short vowels rather than long vowels, and that for all the speakers, except WM where preaspiration approaches normativity (in Helgason's 2002 sense) the median value is higher before short vowels.

For all of the speakers together 49.5% of the fortis stops with previous short vowels receive preaspiration whereas the percentage of fortis stops with preceding long vowels that receive preaspiration is 22%. An example of this breathy voice or devoicing before fortis consonants is given in figure 35 from the speaker SF from Brokenhead.

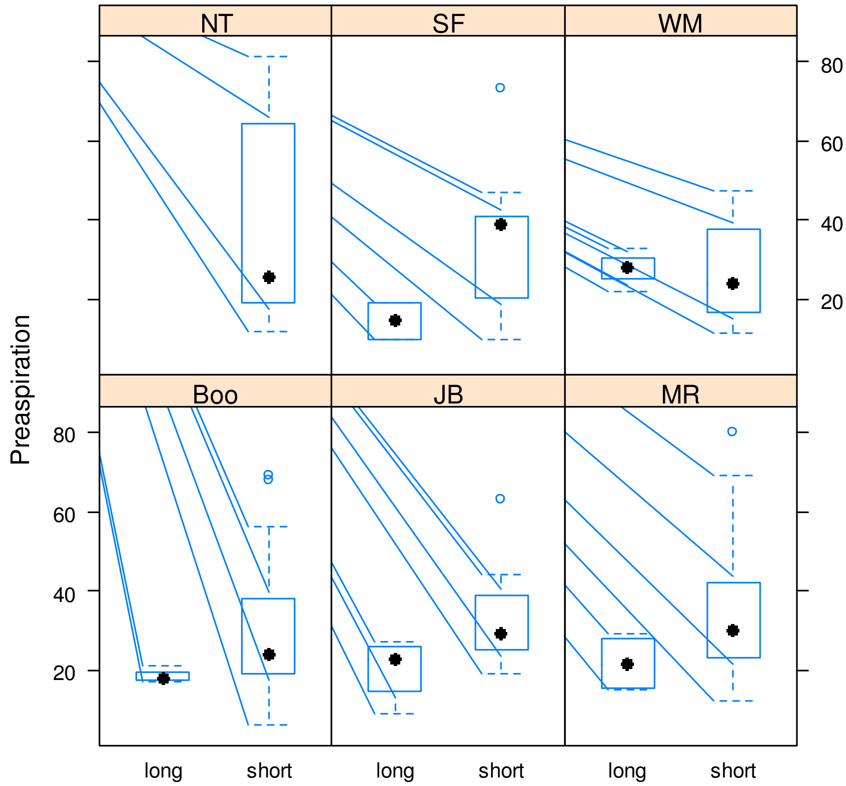


Figure 34 . Duration of preaspiration in ms before long and short vowels by Speaker.

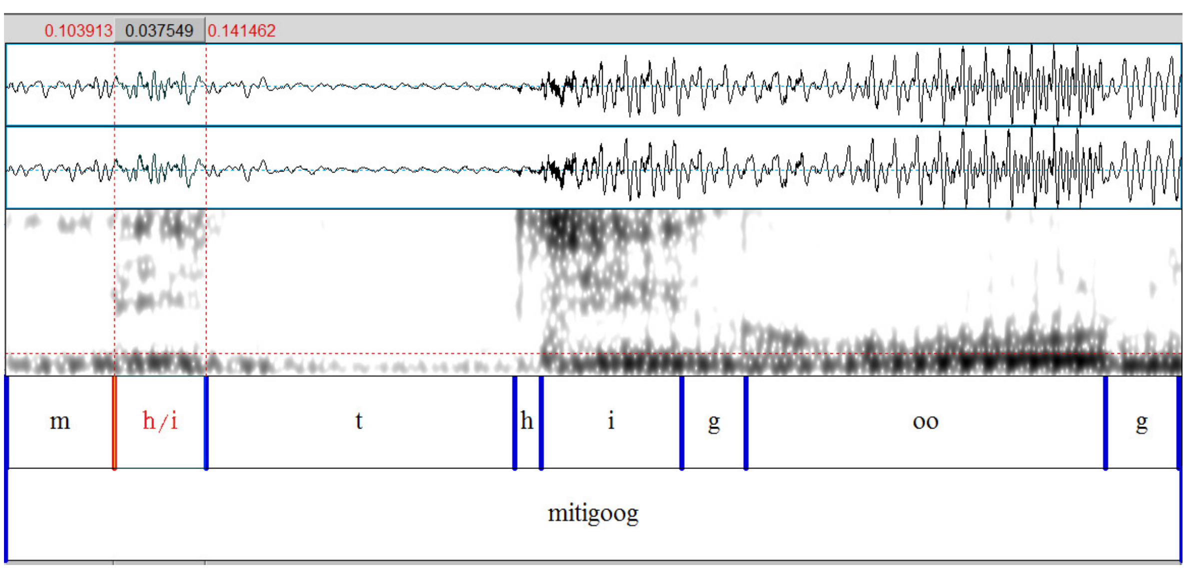


Figure 35. Spectrogram and waveform for mi*tigoog 'trees' produced by Stan Flett from Brokenhead. There is* approximately 38 ms of preaspiration. Weak vowel formants are still visible during the aspirated segment.

5.2.4. Voicing

The sonority value is a non-normative correlate of the /d/-/t/ contrast. Fortis /t/ is never voiced (sonority = 0 in all cases). Lenis /d/ is often voiceless (sonority=0 in many cases), and thus the data structure is quasi-separate for sonority. Figure 36 gives histograms for /d/ according to sonority value by speaker. Table (42) gives the proportions of lenis /d/s falling in each of the sonority values.

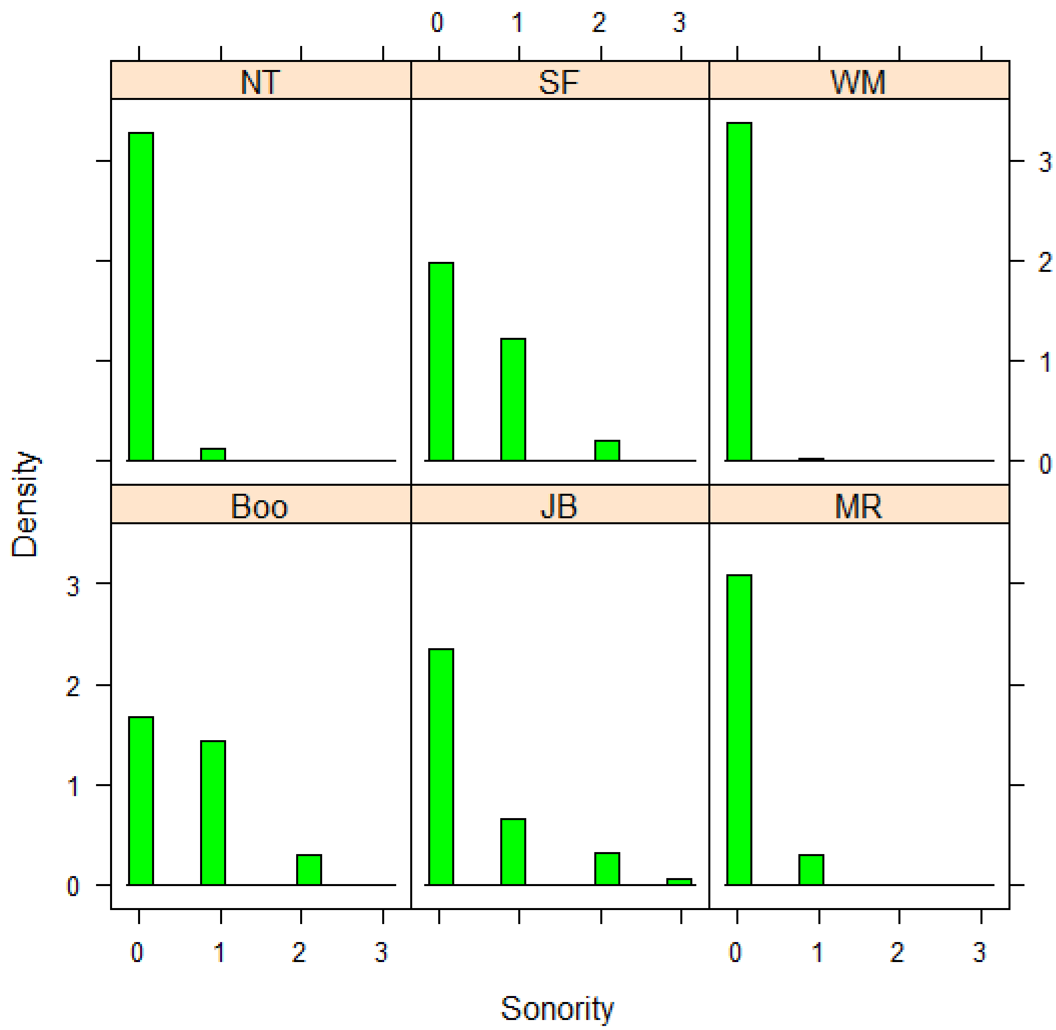


Figure 36. Histograms for the density of /d/s falling in each sonority value by speaker.

(42) Proportions of /d/ falling in each sonority value by speaker.

	0	1	2	3	4	5
NT	.93	.07	0	0	0	0
Boo	**.19**	.67	.14	0	0	0
SF	.35	.55	.095	0	0	0
JB	.54	.29	.135	.03	0	0
WM	**.985**	.015	0	0	0	0
MR	.86	.14	0	0	0	0

Based on these data it appears that sonority is the best correlate for the /d/-/t/ contrast for Boo. For Boo a substantial amount of /d/ tokens have a sonority value above 0 (81%). On the other extreme for WM almost every single /d/ token has a sonority value of 0, the same as every /t/ token. If we compare this to figure 25 (pg. 65) for the sonority values of lenis /b/ it is obvious that voicing is not as good a predictor for the /d/-/t/ contrast as it is for the /b/-/p/ contrast. In general a larger proportion of lenis /d/s have a sonority value of 0 compared to /b/s. Only Boo has lenis /d/s with a substantial amount of voicing on lenis /d/s. Note also that JB's sonority value was an extremely strong predictor for the /b/-/p/ contrast. Here most of his lenis /d/ tokens fall in the 0 sonority range.

Loglinear models did not even converge for NT or WM. In the loglinear models Sonority came out as significant for Boo ($p<0.0001$), SF ($p=.0005$) and JB ($p=.0049$). It came out as barely nonsignificant for MR ($p=.0588$).

The sonority value is an overly coarse measurement. In most cases even for speakers where there are almost no fully voiced /d/s, periodic glottal vibrations seep into the the stop from the preceding vowel. Intuitively, however, the voicing measurement intensities correspond to the difference in sonority values at least for the two speakers for whom it was measurable. For Boo the mean intensity is .777 (sd=.0667) and for NT it is lower at .4479 (sd=.0742).

5.2.5. Loglinear Models I: Factors

In this section we compare the different measures of contrast precision along each of the relevant parameters for the /d/-/t/ contrast. We rank the speakers in terms of the importance of each correlate based on these measures of contrast precision investigating to what degree these rankings correspond with the more basic statistical descriptions given above (e.g. proportional difference between means, proportions of preaspirated segments, etc…) and with each other. Where we see noncorrespondences between these different measurements we try to explain them based on the statistical structure of the categories for each speaker. Although overall the patterns correspond, there is often much discordance between the rankings because the variation between certain speakers can be quite subtle. We limit our scope to discussing the speakers with the worst and best models for a given correlate in the particular rankings on contrast precision. When the rankings of these speakers do not correspond we attempt to explain why this is the case.

5.2.5.1. Consonant Duration

The measurements of contrast precision for dental/alveolar stops on the consonant duration parameter are given in (43). The rankings of speaker by measurement are given in (44).

(43) Measures of contrast precision for /d/ vs. /t/ on consonant duration by speaker.

	Proportional difference	R^2	τ	Slope	Accuracy
NT	1:1.2	.1163	.2709	.0080	.5500
Boo	1:1.6	.4100	.5188	.0139	.7635
SF	1:1.3	.2289	.3698	.0126	.6434
JB	1:1.7	.5046	.5335	.0164	.8412
WM	1:1.3	.2562	.4074	.0134	.6909
MR	1:1.4	.2180	.3712	.0111	.6571

(44) Rankings of speakers by measure of contrast precision in (43).

	Proportions	R^2	τ	Slope	Accuracy
WORST	NT	NT	NT	NT	NT
	MR	**MR**	**SF**	**MR**	**SF**
	SF	**SF**	**MR**	**SF**	**MR**
	WM	WM	WM	WM	WM
	Boo	Boo	Boo	Boo	Boo
BEST	JB	JB	JB	JB	JB

The measurements of contrast precision all correspond with regards to the ranking of the worst and the best predictors.[49] The ranking is still not perfect however. SF has a lower τ coefficient than MR. The consonant duration for MR's /d/ has a larger standard deviation in relation to its

[49] Noteworthy is the fact that MR had consonant duration as one of the best predictors for bilabial stops, but is now one of the ranked second worst for this correlate in dental/alveolar stops. WM was ranked worst for bilabials but is now third best. These POA asymmetries are briefly discussed in the final discussion.

mean than SF's /d/ does (MR: .31, SF: .25), and thus we would expect that there is more discordance for SF.

5.2.5.2. Postaspiration

The measures of contrast precision for the /d/-/t/ contrast on the parameter of postaspiration by speaker are given in (45). The rankings of the speakers by measure are given in (46). Duration ratio refers to the ratio of the mean values of postaspiration in fortis over lenis alveolar/dental stops. Recall that for bilabials we used the difference in proportions which referred to the proportion of lenis or fortis stops that had any postaspiration. Since lenis /d/ consistently has some postaspiration 73 to 95 percent of the time (cf. section 5.2.2.) it is more appropriate to use proportional difference to describe the contrast as we did with closure duration.

(45) Measures of contrast precision for /d/ vs. /t/ on postaspiration by speaker.

	Proportional difference	R^2	τ	Slope	Accuracy
NT	1:1.1	.0105	.0640	.0115	.5286
Boo	1:2.3	.4741	.5601	.0602	.7903
SF	1:1.4	.0770	.2592	.0119	.5502
JB	1:1.1	.1350	.0717	.0058	.5100
WM	1:1.1	.0224	.1456	.0137	.5461
MR	1:1.3	.0368	.1449	.0141	.4877

(46) Rankings of speakers by measure of contrast precision.

	Proportions	R^2	τ	Slope	Accuracy
WORST	NT	NT	NT	JB	NT
	JB	WM	JB	NT	WM
	WM	MR	MR	SF	MR
	MR	SF	WM	WM	SF
	SF	JB	SF	MR	JB
BEST	Boo	Boo	Boo	Boo	Boo

Postaspiration was the worst predictor of the contrast for NT compared to the other speakers, except for slope where JB had an even less successful model. We can attribute this to the fact that JB's categories overlap more because the standard deviations of postaspiration are 23.4 ms for /d/ and 37.4 for his fortis. For NT the standard deviations were much smaller at 3.9 ms for /d/ and 5.2 ms for /t/. Boo has the highest contrast precision on the postaspiration parameter out of all the speakers.

5.2.5.3. Preaspiration

(47) gives the measurements of contrast precision for the /d/-/t/ contrast on the preaspiration parameter. (48) give the rankings of speakers by measure. Proportion in the following chart refers to the proportion of preaspirated fortis /t/. Lenis stops never have preaspiration.

(47) Measure of contrast precision for /d/ vs. /t/ on preaspiration by speaker.

	Proportion	R^2	τ	Slope	Accuracy
NT	.50	.3195	.5450	.04835	.7500
Boo	.49	.3312	.5168	.09485	.7411
SF	.27	.1777	.4086	.05380	.6373
JB	.26	.1695	.4021	.04490	.6300
WM	.56	.3925	.5895	.06405	.7736
MR	.48	.3625	.5840	.05900	.7404

(48) Rankings of speakers by measure of contrast precision in (47).

	Proportions	R^2	τ	Slope	Accuracy
WORST	**JB**	**JB**	**JB**	**JB**	**JB**
	SF	SF	SF	NT	SF
	MR	NT	Boo	SF	MR
	Boo	Boo	NT	MR	Boo
	NT	MR	MR	**WM**	**NT**
BEST	**WM**	**WM**	**WM**	**Boo**	**WM**

JB ranks the lowest for the strength of preaspiration for the /d/-/t/ contrast compared to other speakers. WM ranks the highest on preaspiration for all of the measures of contrast precision except for Slope. Boo has the sharpest slope. Unfortunately this difference has little to do with the measures of contrast precision per se and more to do with the relative amount of lenis or fortis tokens for each of these speakers. Boo has 57 /t/s and 95 /d/s in my data. WM has 54 /t/s and 64 /d/s. Since /d/ never has preaspiration a higher amount of /d/s will shrink the variance along this parameter and make the coefficient larger as a result (Gelman & Hill 2007). Thus, the difference can be accounted for with relation to the different proportions of lenis to fortis tokens in WM and Boo. If we standardize the variables in relation to their proportional frequency (lenis/fortis), this difference can be controlled for to a certain extent. In this case Boo's slope is .0262 and WM's is larger at .0288.

5.2.5.4. Sonority

The measures of contrast precision for the /d/-/t/ contrast on the sonority parameter are given in (49). Rankings of the speakers by measure are given in (50). Proportion in the following table refers to the proportion of lenis /d/s that have a sonority value above 0. Intuitively the higher this value is the better the correlate should be for the speaker. We do not discuss d' in this section because the Sonority value is quasi-separate in our data (cf. section 4.2. of this thesis). The models did not converge for NT and WM, thus the slope could not be computed.

(49) Measures of contrast precision for /d/ vs. /t/ on sonority by speaker (Proportion refers to the proportion of lenis /d/s that have a sonority value above 0).

	Proportion	R^2	τ	Slope	Accuracy
NT	.07	__	.1826	__	.5000
Boo	.81	.6155	.7375	-1.5169	.9053
SF	.65	.3793	.5944	-1.2630	.8245
JB	.44	.2129	.4425	-1.0031	.5000
WM	.015	__	.0849	__	.5000
MR	.14	.0483	.2304	-.7110	.5000

(50) Rankings of speakers by measure of contrast precision in (49).

	Proportions	R^2	τ	Slope	Accuracy
	MR	MR	MR	MR	MR
	JB	JB	JB	JB	JB
	SF	SF	SF	SF	SF
BEST	**Boo**	**Boo**	**Boo**	**Boo**	**Boo**

The models did not converge for NT and WM. All of the measures of contrast precision correspond exactly in this case in terms of the rankings in (50).

5.2.6. Loglinear Models II: Multiple Regression

In this section I use multiple regression to assess the main hypothesis stated in chapter 3, that contrasts between lenis-fortis sets as category systems have close to the same degree of contrast precision. I try to fit the best model for each speaker using the AIC (Burnham & Anderson 2002, Anderson 2008). In each section I start with what I will call "the basic model" which consists of an additive multiple logistic regression model with all of the factors discussed in the previous section. Based on the results of the basic model, nonsignificant factors are removed and suspected interactions are added until the best model is achieved (according to the lowest AIC). I then compare the models for all the speakers and discuss the different degrees of contrast precision according to measure for each speaker. The counts of tokens for dental/alveolar stops by speaker are given in (51).

(51)

	Boo	JB	MR	NT	SF	WM
t	57	50	52	28	51	54
d	95	103	95	30	94	64

5.2.6.1. NT: /d/-/t/

Results for the basic model for NT's /d/-/t/ contrast are given in (52). The AIC is 62.52.

(52) Basic model for NT: /d/-/t/

Estimate Pr(>|z|)

(Intercept)	-4.3043	0.0775	
ConsDur	0.0154	0.3008	
PostAsp	0.0998	0.2598	
PreAsp	0.1584	0.0475	*
Sonority	-0.5233	0.7890	

A model where all nonsignificant factors are removed has an AIC of 60.14. This is the best model, presented in (53).

(53) Best model for NT: /d/-/t/

	Estimate	Pr(>|z|)	
(Intercept)	-0.7346	0.0223	*
PreAsp	0.1934	0.0317	*

5.2.6.2. Boo:/d/-/t/

The basic model for the /d/-/t/ contrast in Boo is presented in (54). The AIC is 35.936.

(54) Basic model for Boo: /d/-/t/

	Estimate	Pr(>|z|)	
(Intercept)	-8.9126	0.0002	***
ConsDur	0.0544	0.0009	***
PostAsp	0.1897	0.0056	**
PreAsp	0.1632	0.0719	
Sonority	-4.0344	0.0108	*

After preaspiration was removed the AIC rose to 42.52. A two way interaction between consonant duration and postaspiration was not significant (p=.3663). Another two way interaction between consonant duration and sonority was not significant (p=.6847). Thus, the basic model is the best model for Boo. An alternative model which has an AIC of 35.937 (.001

higher than the basic model) does not contain preaspiration, instead it has a nonsignificant interaction term between consonant duration and preaspiration. The results of this alternative model are presented in (55). We still use the basic/best model for Boo, however.

(55) Alternative model for Boo: /d/-/t/

	Estimate	Pr(>|z|)
(Intercept)	-8.9618	0.0001 ***
ConsDur	0.0538	0.0009 ***
PostAsp	0.1956	0.0047 **
Sonority	-4.0166	0.0110*
ConsDur:PreAsp	0.0019	0.0867

5.2.6.3. SF: /d/-/t/

The basic model for the /d/-/t/ contrast for SF is given in (55). The AIC for this model is 92.73.

(55) Basic model for SF: /d/-/t/

	Estimate	Pr(>|z|)
(Intercept)	-5.1559	0.0008 ***
ConsDur	0.0362	0.0049 **
PostAsp	0.0683	0.0039 **
PreAsp	0.1279	0.0386 *
Sonority	-4.2342	0.0057 **

If we remove any of these factors the AIC increases. No significant two way interactions were found for SF. Thus, we accept the basic model as the best for this speaker.

5.2.6.4. JB: /d/-/t/

The basic model for the /d/-/t/ contrast for JB is given in (). The AIC for this model is 87.27.

(56) Basic model for JB.

	Estimate	Pr(>|z|)	
(Intercept)	-6.2145	1.63e-05	***
ConsDur	0.0604	1.34e-06	***
PostAsp	-0.0252	0.3502	
PreAsp	0.1481	0.0178	*
Sonority	-2.6784	0.0616	

When nonsignificant factors are removed the AIC increases to 93.41. When Sonority is readded the AIC is smaller than the basic model's at 87.27. No two way interaction terms were significant, and adding interaction terms increased the AIC.

(57) Best model for JB: /d/-/t/

	Estimate	Pr(>|z|)	
(Intercept)	-6.8531	6.88e-07	***
ConsDur	0.0608	1.47e-06	***
PreAsp	0.1423	0.0210	*
Sonority	-2.5777	0.0790	

5.2.6.5. WM: /d/-/t/

The basic model for the /d/-/t/ contrast for WM did not converge. Recall that a model that just contained sonority did not converge either. The basic model without sonority is presented in (58). The AIC is 80.24.

(58) Best model for WM: /d/-/t/

	Estimate	Pr(>|z|)	
(Intercept)	-11.3728	1.64e-05	***
ConsDur	0.0764	2.03e-05	***

PostAsp	0.0619	0.2864
PreAsp	0.2969	0.0011 **

When nonsignificant factors were removed the AIC dropped to 79.55. Results for this model are presented in (59).

(59) Best model for WM: /d/-/t/

	Estimate	Pr(>|z|)
(Intercept)	-10.2322	6.47e-06 ***
ConsDur	0.0766	2.35e-05 ***
PreAsp	0.3001	0.0012 **

The multiplicative model showed a significant interaction between consonant duration and sonority (p=.0037). The AIC for this model was higher, however, at 82.19. We therefore tentatively choose the model given in (59).

5.2.6.6. MR: /d/-/t/

The results of the basic model for the/d/-/t/ contrast for WM are given in (60). The AIC is 65.61.

(60) Basic model for MR: /d/-/t/

	Estimate	Pr(>|z|)
(Intercept)	-8.2527	1.12e-05 ***
ConsDur	0.0553	0.0002 ***
PostAsp	0.1366	0.0103 *
PreAsp	0.1864	0.1081
Sonority	-1.0337	0.5609

When nonsignificant factors are removed the AIC increased to 75.84. When preaspiration was readded the AIC decreased to 64.38. The results for this model are presented in (61). This was the best model. No significant interactions were found.

(61) Best model for MR: /d/-/t/

	Estimate	Pr(>|z|)	
(Intercept)	-8.3188	1.12e-05	***
ConsDur	0.0549	0.0002	***
PostAsp	0.1433	0.0079	**
PreAsp	0.2131	0.1083	

5.2.6.7. Summary: Contrast Precision between Complex Categories: /d/-/t/

In this section we compare the speakers in terms of the contrast between /d/ and /t/ as complex categories. An overview of the most important predictors for each speaker is given in (62). The numbers in each of the cells represents the coefficient for the predictor with all the variables standardized (the mean subtracted from the value divided by the standard deviation). Recall we cannot compare the AIC between speakers directly. Each speaker has a different count of /d/s and /t/s. The AIC value depends on information entropy (i.e. how much information is lost be the model), and thus it is contingent on sample size.

The table in (62) contains coefficients associated with each factor involved in the model with each variable standardized. The coefficients for the predictors represent the values when all of the other predictors are at their mean. The units are also standardized so it is easier to compare their relative importance in a particular speaker's model. However, since the variables do not have all of the same distributional structures (when compared to each other and possibly when compared across speakers) the coefficients do not directly represent the relative importance of each cue in each speaker's model. The coefficients are too contingent on their relationship to other variables.

(62) Overview of /d/ vs. /t/ as complex categories by speaker.

	ConsDur	PostAsp	PreAsp	Sonority
NT			4.022	
Boo	2.175	2.088	2.069	-2.574
SF	.8555	.9096	1.380	-2.594
JB	2.332		1.309	-1.912
WM	1.856		3.806	
MR	1.455	.6187	3.715	

There are two senses in which the speakers have different models for predicting the /d/-/t/ contrast. First, the best model contains different acoustic correlates as factors depending on the speaker. For example, WM's best model contains only consonant duration and preaspiration whereas MR's best model contains these factors in addition to postaspiration. Second, the strength of each predictor for making the contrast between /d/-/t/ varies from speaker to speaker. Boo and SF have the same model in the first sense but different models in the second sense. This is not attributable to differential weighting of acoustic cues. Boo had a higher contrast precision than SF for every correlate when the dimensions were considered individually. This seems to be reflected in the coefficients for the multivariate analysis as well. Recall that Boo's data were from elicitation and SF's were from conversation. Unless there are other predictors which I did not investigate which are stronger for SF than for Boo, the difference between these speakers correspond with the general findings of H & H theory (Lindblom 1992, Moon & Lindblom 1994). In elicitation Boo is using hyperspeech and thus has stronger acoustic correlates to the /d/-

/t/ contrast. SF is further down on the hypospeech end of the continuum and thus many of the acoustic correlates are obliterated due a bias towards more efficient articulatory drives (cf. Boersma 1998 as well). Boo is making the contrast more strongly on each of the dimensions. Figure 37 gives the loglinear curves for Boo (solid) and SF (dashed) on consonant duration with all other factors at 0. SF has a shallower line and thus a higher probability of confusion over this parameter. There is less certainty associated with the classification of his tokens. Figure 38 gives the loglinear curves for Boo (solid) and SF (dashed) on postaspiration with consonant duration at 80 ms and preaspiration and sonority at 0.

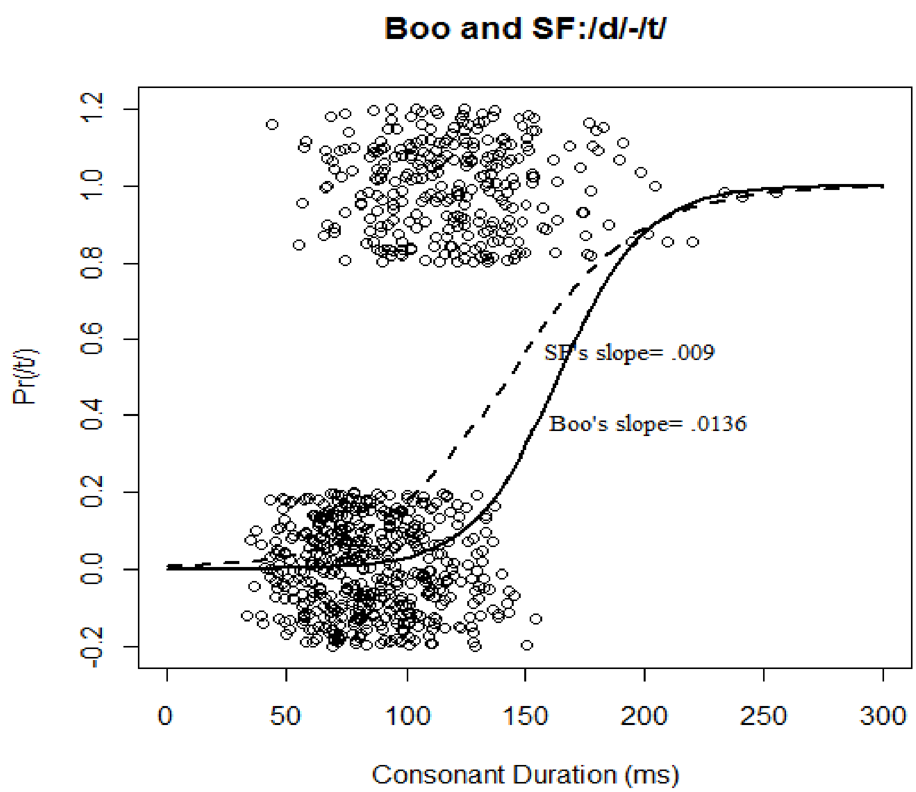


Figure 37. Loglinear curves for Pr(/t/) on consonant duration with postaspiration, preaspiration and sonority at 0 for Boo (solid) and SF (dashed).

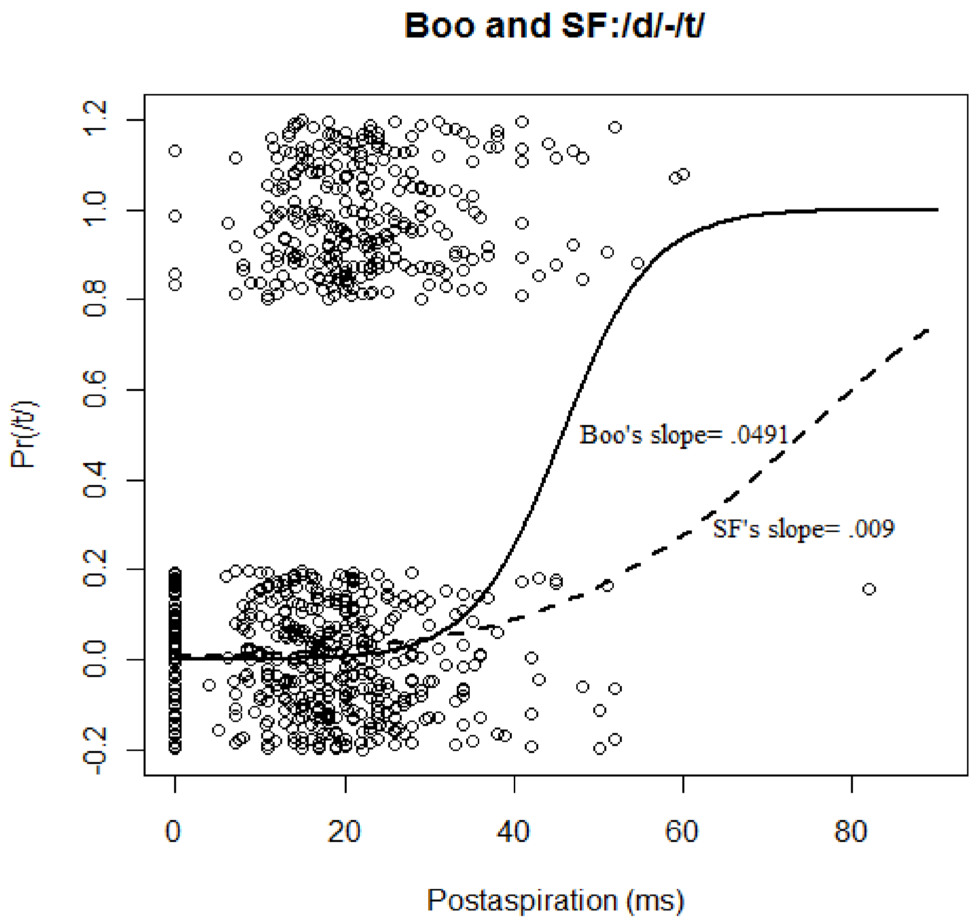
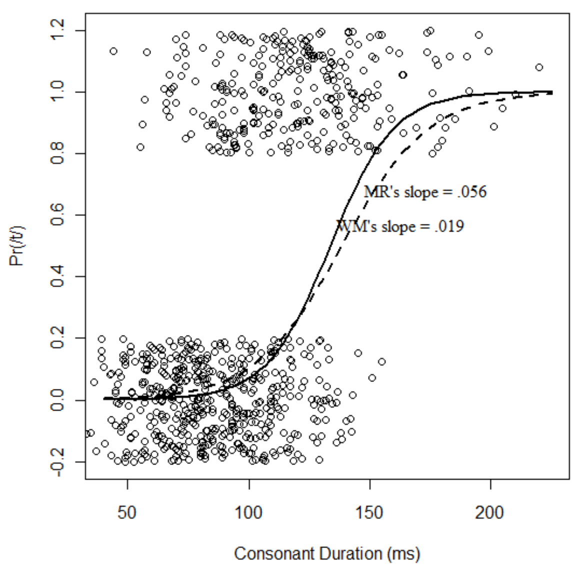


Figure 38. Loglinear curves for Pr(/t/) on postaspiration with consonant duration at 80 ms, preaspiration at 0 ms and sonority at 0.

A comparison between Boo and SF who appear to use the same dimensions in marking the /d/-/t/ contrast shows that there is an obvious difference in robustness according to speech style. Boo naturally uses more hyperspeech, and SF more hypospeech. A comparison of MR and WM potentially shows a different situation. Based on the standardized coefficients it looks as if MR uses postaspiration to the detriment of her other correlates. WM's consonant duration and preaspiration coefficients are larger than MR's, suggesting that he is relying more on just these two dimensions. Figure 39a gives the loglinear curves for WM and MR on consonant duration when postaspiration and preaspiration are 0. Figure 39b gives the loglinear curves for WM and MR on preaspiration when postaspiration is 0 ms and consonant duration is 90 ms. In both cases

WM's curves (solid) are steeper than MR's (dashed) indicating that he is able to predict the /d/-/t/ contrast more accurately on these parameters. The fact that MR has postaspiration in her model as an additional parameter suggests that she is using this correlate to compensate for the weaker predictability associated with her other parameters.



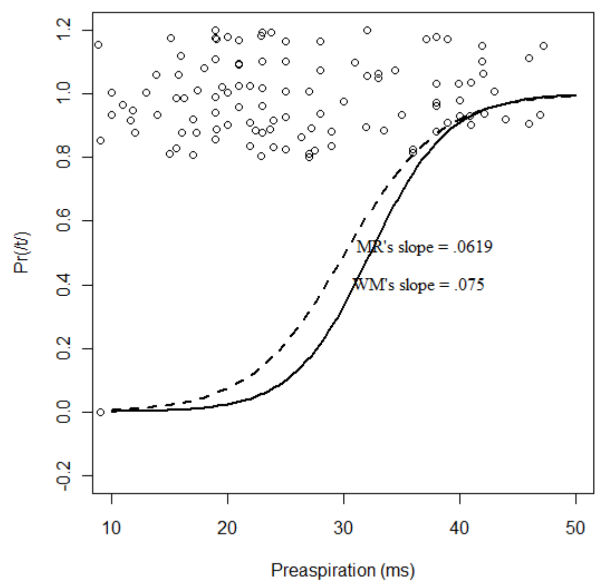


Figure 39a. Loglinear curves for Pr(/t/) on consonant duration with postaspiration and preaspiration at 0 for WM (solid) and MR (dashed). Figure 39b. Loglinear curves for Pr(/t/) on preaspiration with consonant duration at 90 ms and postaspiration at 0 for WM (solid) and MR (dashed).

The Accuracy measurements of contrast precision for the contrast between /d/ and /t/ as complex categories are presented in (63) by speaker. These are compared to the Accuracy values which were measured by considering one correlate at a time. Unfortunately preaspiration and sonority cannot be adequately calculated.

We have already observed the sense in which the speakers have different models of the /d/-/t/ contrast. The Accuracy measurements support the idea that the speakers have close to the same level of contrast precision between category systems, but with a few caveats. First Boo should be looked at as separate from the group because his data are from elicitation and thus he was most likely exaggerating acoustic correlates. Postaspiration is a bad predictor in general because /d/ is postaspirated so often. Therefore the variation within this parameter should be ignored. There is larger variation in Accuracy on consonant duration, preaspiration and sonority than between the complex categories. These differences suggest that the thesis is essentially correct.

(63) Accuracy for /d/-/t/ contrast by speaker (rows) on multidimensional space (columns).

	ConsDur	PostAsp	PreAsp	Sonority	Best
NT	.5500	.5286	.7500	.5333	.7500
Boo	.7635	.7903	.7411	.9053	.9732
SF	.6434	.5502	.6373	.8245	.8381
JB	.8412	.5100	.6300	.6000	.8957
WM	.6909	.5461	.7736	.5000	.9011
MR	.6571	.4877	.7404	.5000	.8231
Range (with Boo)	.6434-.8412	.4877-.7903	.6300-.7736	.5000-.9053	.8231-.9732
Range (without Boo)	.6571-.8412	.4877-.5461	.6300-.7736	.5000-.8245	.8231-.9011

It is important to emphasize the tentativeness of this conclusion. There are other acoustic correlates we have not taken into account (cf. Lisker 1986), as discussed in the section on bilabials. In particular it may be the case that spectral differences in the postaspiration after the burst might be marking the /d/-/t/ contrast. As I have already stated, /d/ seems to have breathy voice much more often than /t/. This would be an odd contrast to make since it seems to go against the grain of feature economy, but it is a real possibility. Furthermore the sonority value is an extremely coarse measurement of voicing. In fact when vocal fold vibration could be measured during the closure, the measurements were made. In this case we can measure the ratio of vocal fold vibration to the closure duration. Voicing ratio was significant in a loglinear model with all the speakers pooled ($p<.0001$). Speakers might be using the glottal vibrations that seep into /d/s to mark the contrast.

5.3. Velars: /g/-/k/

This section describes the acoustic correlates of the lenis-fortis contrast in intervocalic velar stops as represented in my elicitation and corpus data. We assess the effect of each correlate individually. I give the means, standard deviation and proportional differences as measured from the means of the frequency distributions between lenis and fortis stops along each of the parameters for each speaker: Consonant duration (5.3.1), postaspiration (5.3.2), preaspiration (5.3.3) and voicing (5.3.4). Then we describe the contrast precision measures from our loglinear regression models for each parameter examining the extent to which these parameters correspond (5.3.5). The second loglinear section discussed the contrast when lenis and fortis stops are viewed as category systems containing all the afore mentioned dimensions simultaneously (5.3.6). I choose the best model for each speaker.

5.3.1. Consonant Duration

As noted in section 4.2.4 some consonant tokens are assigned a consonant duration of 0 ms. This corresponds to a Sonority level of 4 or 5. In these cases I was unable to detect any discernible boundary between the consonant and the flanking vowels (Sonority=4), in some cases I was unable to even hear the consonant (Sonority=5). This phenomenon never occurs with alveolar lenis /d/ and rarely with bilabial lenis /b/ but is quite frequent with lenis velar /g/ in the speech of at least three of the speakers. It is unlikely that the tokens which are recorded as having 0 ms of consonant duration represent complete elision in each case, at least articulatorily. Reason to believe this might come from the fact that the data are almost normally distributed for the speakers but drop off suddenly around 20 ms (figure 40). There are two perspectives we can adopt. Either 0 ms is the best approximation of the consonant duration for these tokens and should be left in or tokens which display this characteristic should be removed because their appearance is due solely to problems with measurement. Although the latter approach might seem like the obvious one, the former has some justification in that the unobservability of lenis velars may in some cases correspond to their lack of perceptual salience. Evidently /g/s are dropping out some of the time. The translator and native speaker of Saulteaux Roger Roulette transcribes the expression “you know” gi-gikendaan as igikendaan for some speakers where the /g/ never appears in this expression, despite being a morpheme that in principle contains much semantic content (gi- is the 2nd person prefix in the independent form). The following is a sentence from Stan Flett (Brokenhead) transcribed by Roger Roulette.

(64) Fifteen dollars naanigoding. Ngii-ni—maawanjiʔaaʔ **igikendaan.**
fifteen dollars naanigoding n-gii-ani-maawanji-aa-ʔ **igikendaan**
fifteen dollars pc.sometimes 1-PST-ALONG-save.TA-DIR-3.PL exp.you.know
‘Sometimes fifteen dollars. I saved as I went along, you know.’ (Roulette 1997: SF; p.10)

We save a presentation of the data of lenis velar syncopation for the section on voicing. Here we present data with the 0 ms tokens because it appears to be an important source of variation among speakers even if the exact measurement is slightly less accurate.

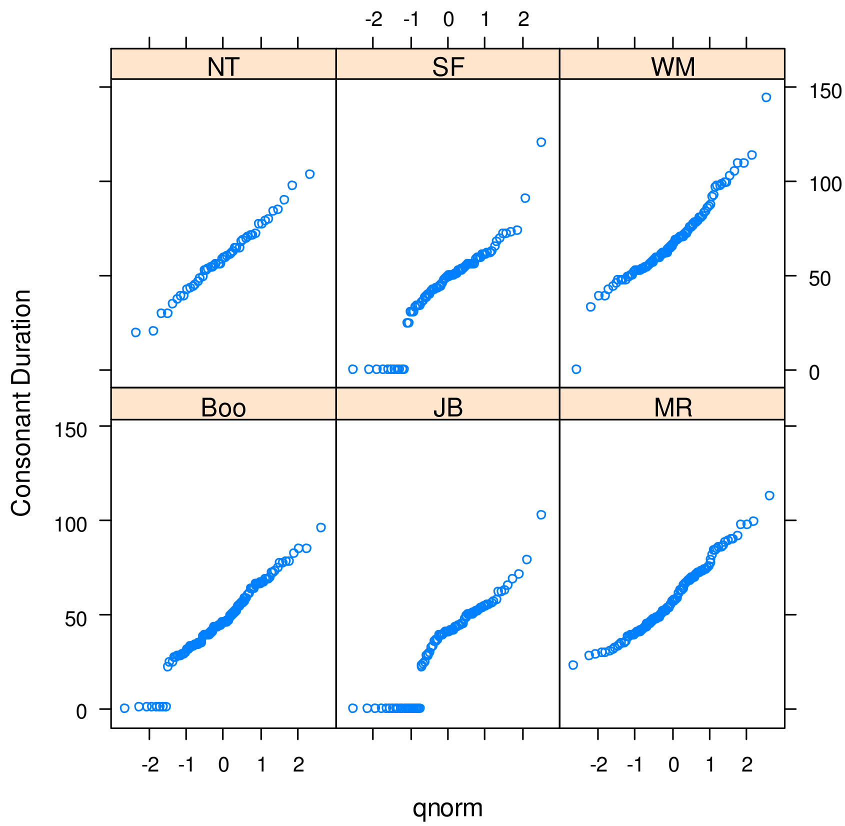


Figure 40. Quantile-quantile plots for consonant duration in lenis velar stops by speaker. Observe that for Boo, JB and SF the frequency distributions drop off around the first quartile and all become 0 ms.

Some tokens of fortis velar /k/ were recorded with 0 ms of consonant duration. This occurs when it is realized as the velar fricative /x/. The entire duration of this fricative is counted as preaspiration for this study. The reason is that in many cases preaspiration is thought to occur where mostly voiceless glottal frication precedes the closure duration. Fortis velars realized as fricatives can be thought of as preaspirated segments where the stop never reaches its target. Also a segment which is phonetically a fricative corresponds best to the common definition of preaspiration as glottal frication without a downstream air mechanism (Kingston 1990, Silverman 2003). 0 ms values for lenis and fortis velar stops arise from articulatory reduction in hypospeech but the acoustic consequences are different because of the glottal gesture. This phenomenon almost only occurs with Stan Flett (6 of his 75 fortis tokens) (figure 41) but also occurs with Mary Ryle (figure 42).

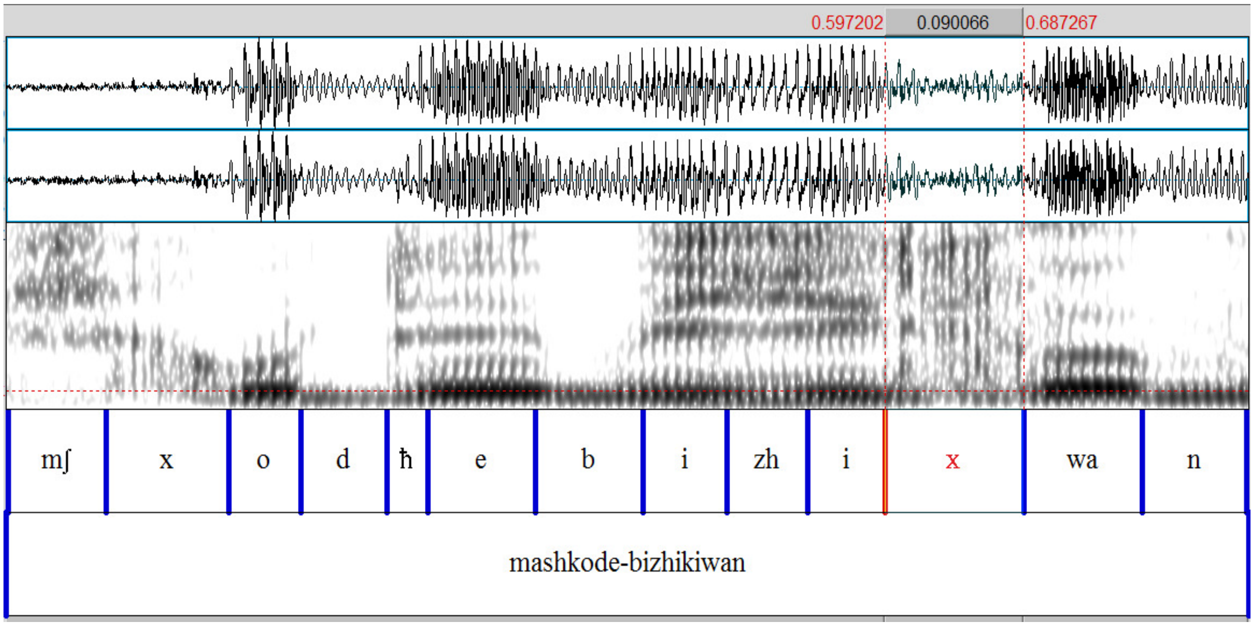


Figure 41. Spectrogram and waveform for mashkode-bizhikiwan *“black cow” from Stan Flett in Brokenhead (SF.* 0009, SF_3_590_900; 860.9). The /k/ is pronounced as a fricative [x] throughout the whole duration. This is recorded as 91 ms of preaspiration with 0 ms of consonant duration.

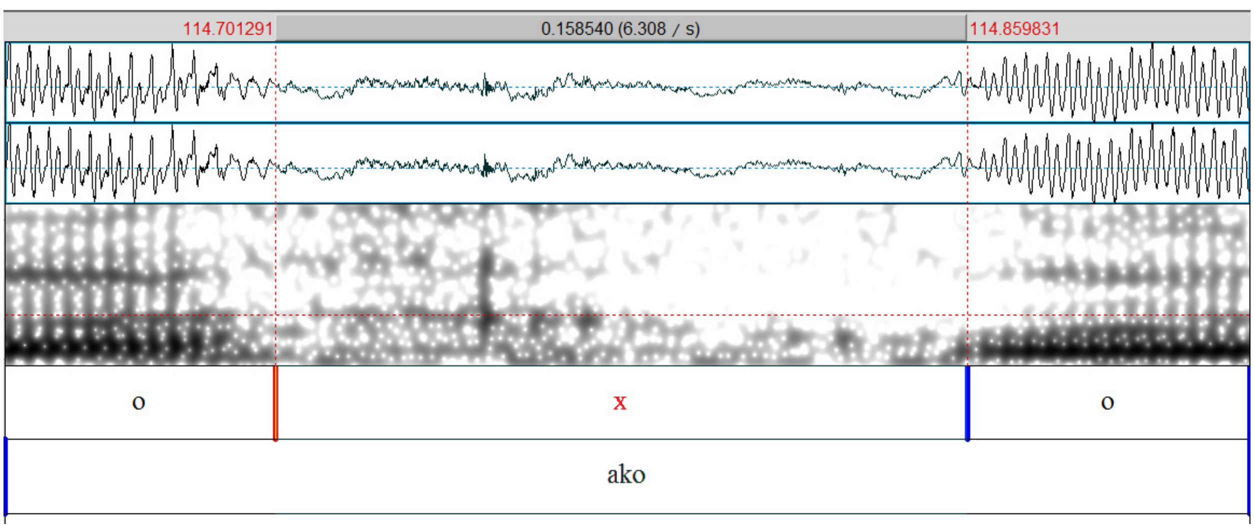


Figure 42. Spectrogram and waveform for ako 'EMPH' from Mary Ryle in Fairford (MR_1_0_300: 114.7). /k/ surfaces as a fricative [x]. This was recorded as 159 ms of preaspiration with 0 ms of consonant duration.

Figure 43 displays the differences in closure duration for velar stops by speaker. (65) gives the mean, standard deviations and proportional differences by speaker. (66) gives these same values with all of the 0 ms tokens removed.

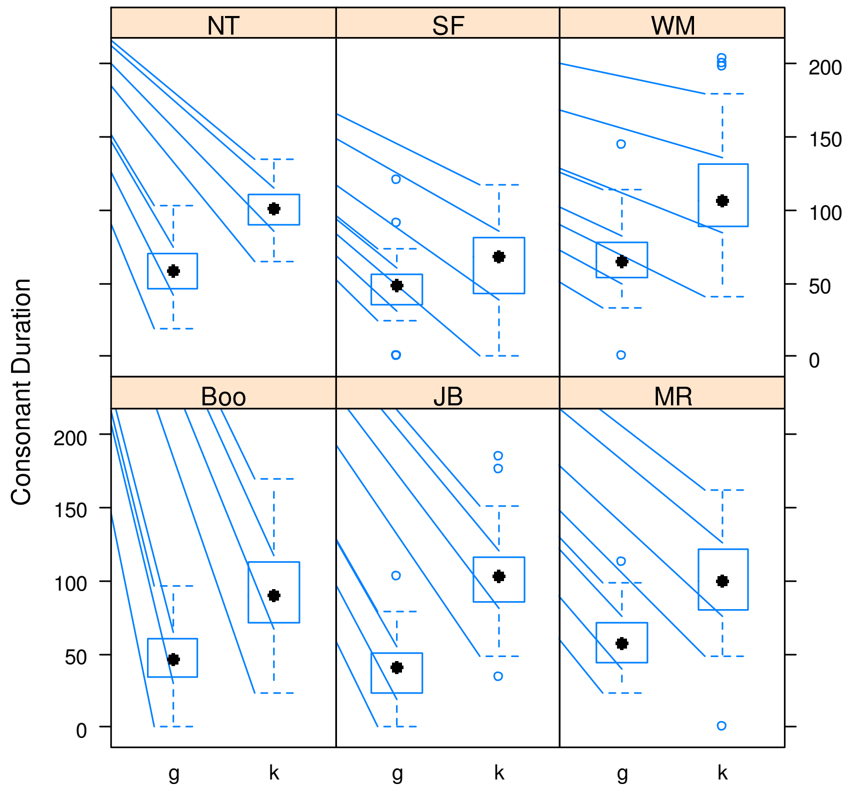


Figure 43. Consonant duration of /g/ vs. /k/ by speaker.

(65) Mean, standard deviation and proportional differences for consonant duration (all data).

	Mean		Standard Deviation		Duration Ratios
	g	k	g	k	
NT	58.6	100.1	18.3	16.5	1:1.7
Boo	46.4	93.1	19.7	29.9	1:2.0
SF	44.3	61.7	22.3	27.7	**1:1.4**
JB	35.2	102.8	22.9	28.2	**1:2.9**
WM	68.1	111.2	20.4	37.6	1:1.6
MR	58.4	102.3	18.6	30.5	1:1.75

(66) Mean, standard deviation, and proportional differences for consonant duration (Consonants recorded as having a duration of 0 ms removed from the statistical description).

	Mean		Standard Deviation		Duration Ratios
	g	k	g	k	
NT	58.6	100.1	18.3	16.5	1:1.7
Boo	46.7	93.1	19.3	29.9	1:2.0
SF	51.0	67.1	15.1	21.6	**1:1.3**
JB	46.0	102.8	13.6	28.2	**1:2.2**
WM	68.8	111.2	19.3	25.5	1:1.6
MR	58.4	103.7	18.6	28.1	1:1.8

The rankings of speakers according to the duration ratios is the same for both (65) and (66), the difference being mostly in how extreme the ratios are for JB (1:2.2 vs. 1:2.9). Fortis velar stops vary from being 1.3 to 2.2 times as long as their lenis counterparts; 1.4. to 2.9 if syncopated /g/s are counted.

5.3.2. Postaspiration

Figure 44 displays boxplots for postaspiration in velar stops by speaker. Separation does not occur because there are values of lenis consonants that have postaspiration, although for most speakers (excepting NT) these values lie outside of the 25-75% quantile range. Figure 45 gives quantile-quantile plots for postaspiration in lenis /g/s. (67) displays the means and standard deviations, proportions and proportional differences for postaspirated lenis and fortis consonants by speaker.

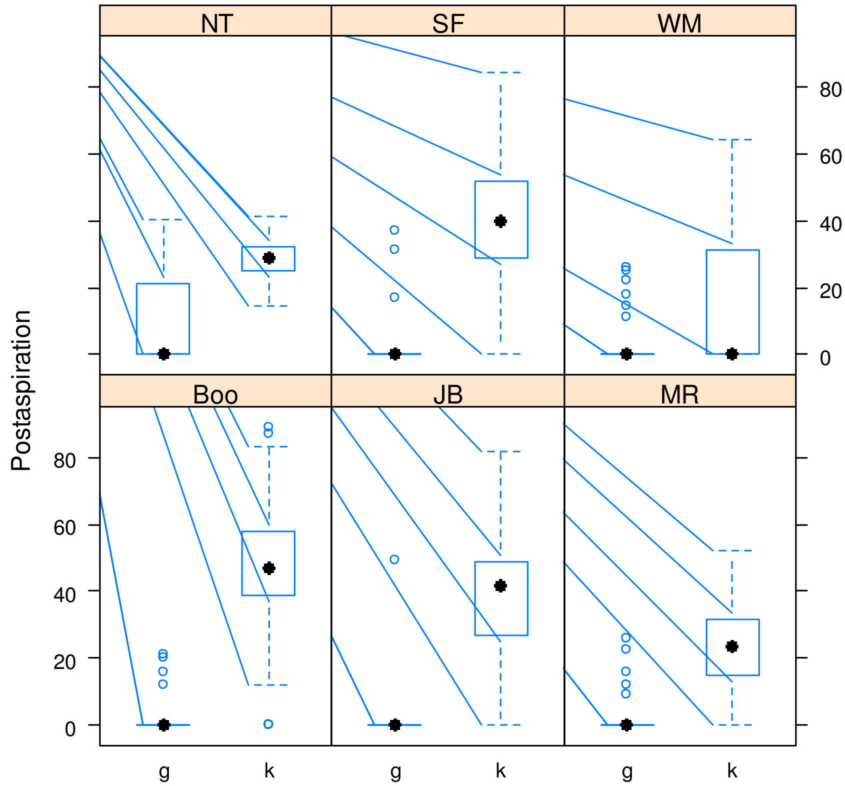


Figure 44. Postaspiration in ms for /g/ vs./k/ by speaker.

(67) Mean, standard deviation and proportions of tokens for postaspiration in velar stops.

	Mean		Standard Deviation		Proportion of Tokens		Proportional difference for /g/-/k/
	g	k	g	k	g	k	
NT	10.5	28.8	13.4	6.2	0.47	1.00	2.7
Boo	2.6	47.4	16.0	16.8	0.030	0.96	18.2
SF	1.0	40.6	5.6	18.3	0.036	0.95	40.6
JB	0.6	38.9	5.2	17.1	0.012	0.94	64.8
WM	1.2	16.2	4.9	18.0	0.060	0.83	13.5
MR	0.75	22.3	3.7	13.9	0.040	0.83	29.7

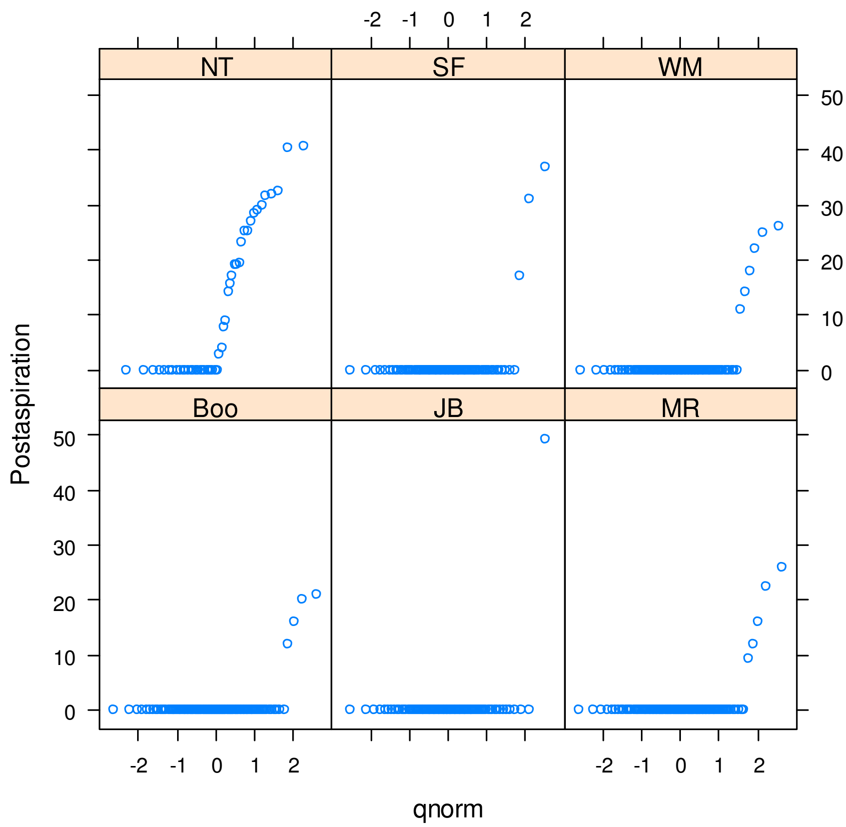


Figure 45. Quantile-quantile plots for postaspiration in lenis velar stops.

5.3.3. Preaspiration

Preaspiration in fortis velar /k/ is a non-normative acoustic correlate (in Helgason's 2002 sense). It is not always present. Preaspiration with respect to the lenis-fortis contrast has a quasi-separate structure. Lenis velar stops never have preaspiration. The quantile-quantile plot in figure 46 gives an idea of the distributional characteristics of preaspiration in velar fortis consonants. As can be seen from figure 45, preaspiration is much more robust overall in fortis velars than in other consonants, but they are still not normally distributed. At least a quarter of their values are clustered at 0 ms. (68) gives the means, standard deviations and proportions of tokens of preaspirated fortis /k/s. Preaspiration was a significant predictor in the loglinear models (NT: p=0.0074; Boo: p<0.0001; SF: p=0.0156; JB: p=0.0102, WM: p=.0013; MR: p<0.0001).

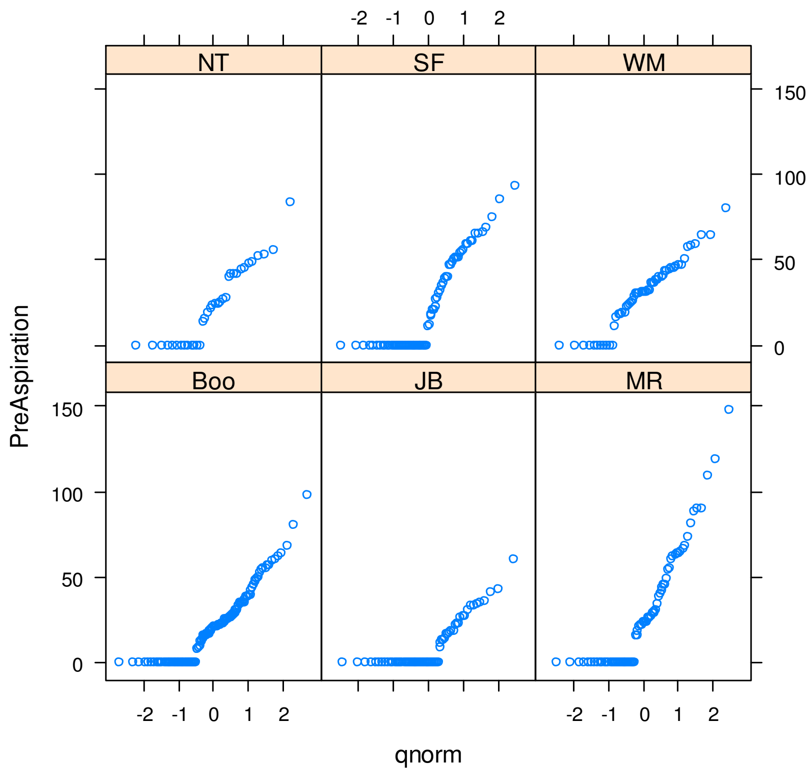


Figure 46. Quantile-quantile plots for preaspiration in fortis velar stops by Speaker.

(68) Mean, standard deviation and proportion of tokens for preaspirated fortis velar stops. (The statistical descriptions in the Overall column are made using all the fortis tokens. The statistical descriptions in the Preasp. column are made using only those fortis tokens that are more than 0 ms in duration)

	Mean		Standard Deviation		Proportion
	Overall	Preasp.	Overall	Preasp.	
NT	23.3	37.1	22.4	16.7	0.63
Boo	20.8	30.4	19.8	19.8	0.69
SF	23.1	45.6	26.95	25.0	0.51
JB	9.7	25.7	14.5	11.95	0.38
WM	29.9	37.0	19.8	14.5	0.80
MR	29.2	49.8	33.7	30.0	0.59

Recall that there was a difference in the amount of preaspiration that occurred with a dental/alveolar fortis stop depending on the previous vowel. We attributed this to differential degrees of reduction of the previous vowel. Figure 47 gives fortis consonants before short and long vowels in terms of their preaspiration by speaker. Again it looks as if short vowels are more prone to devoice and cause a preaspirated fortis consonant. This seems to be true for Boo, NT, MR and SF. Figure 47 is slightly misleading because long vowels before fortis consonants are much less frequent overall. Nevertheless there are proportional differences between the two groups, and in every case, except for WM, fortis consonants preaspirate more before short vowels. This fact makes sense if we consider the literature on Ojibwe stress, which posits that short vowels are often lenited (Piggott 1980, Valentine 1994, 2001). This could correspond to articulatory undershoot in terms of the preconsonantal vocalic laryngeal gesture, increasing the likelihood that voiceless laryngeal coarticulation from the fortis consonant will produce preaspiration.

The differences are fairly substantial for NT, Boo, SF and MR but not for the other speakers. Loglinear models where we attempt to predict the vowel length feature based off preaspiration only come out as significant for Boo (p=.0110), SF (p=.0261) and MR (p=.0274). Models for the other speakers were not significant (NT: p=.4787, JB: p=.7484, WM: p=.0935).

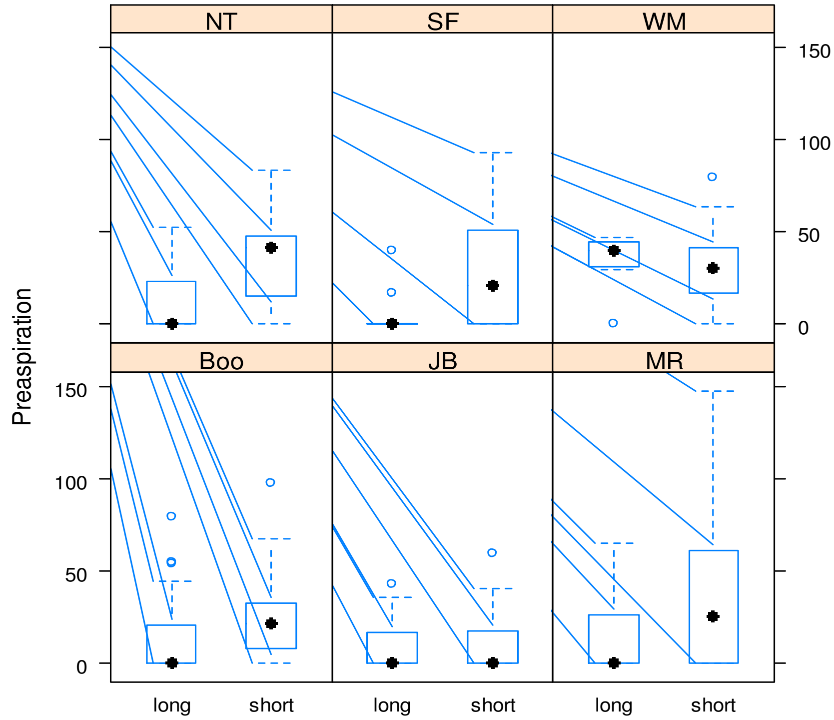


Figure 47. Preaspiration in velar fortis stops before long and short vowels by Speaker.

(46) Token counts and proportions of preaspirated /k/s in relation to vowel length by speaker.

	long preasp./tokens	long percentage of preasp.	short preasp./tokens	short percentage of preasp.
NT	7/17	0.41	15/18	0.83
Boo	13/31	0.42	83/109	0.76
SF	2/17	0.12	36/63	0.57
JB	7/22	0.32	18/44	0.41
WM	6/7	0.86	38/48	0.79
MR	8/19	0.42	36/56	0.64

5.3.4. Voicing

Sonority has a quasi-separate structure in almost all speakers for velars. For Boo Sonority has complete separation. The difference between Boo and the other speakers in this regard may correspond to differences along the hypo-hyper speech continuum (Moon & Lindblom 1994). Recall that Boo's data was gathered from elicitation, and thus it most likely lies closer to the hyperspeech end of the continuum rather than the data from the other speakers which is from conversation (SF, JB, WM, MR) or story telling (NT). On the hyperspeech end of the continuum acoustic correlates will tend to be exaggerated. Thus, if voicing is an important acoustic correlate to the contrast for Boo, then he will exaggerate the extent to which it appears in his speech. There are no substantially voiced fortis /k/s (they all receive a Sonority value of 0). The proportions for each sonority value for each speaker are given in (70). Figure 48 displays the Sonority values for lenis velar stops for each speaker. In the loglinear model the Sonority value was significant for all speakers (NT=.0016; Boo<.0001; SF: p<.0001; JB: p<.0001; WM: p<.0037; MR: p=.0004).

(70) Proportions of /g/ falling in each sonority value by speaker.

	0	1	2	3	4	5
NT	.32	.48	.16	.02	.02	0
Boo	0	.135	.49	.32	.05	0
SF	.02	.17	.42	.265	.07	.05
JB	.01	.06	.13	.56	.10	.13
WM	.57	.34	.07	.01	0	0
MR	.42	.44	.10	.04	0	0

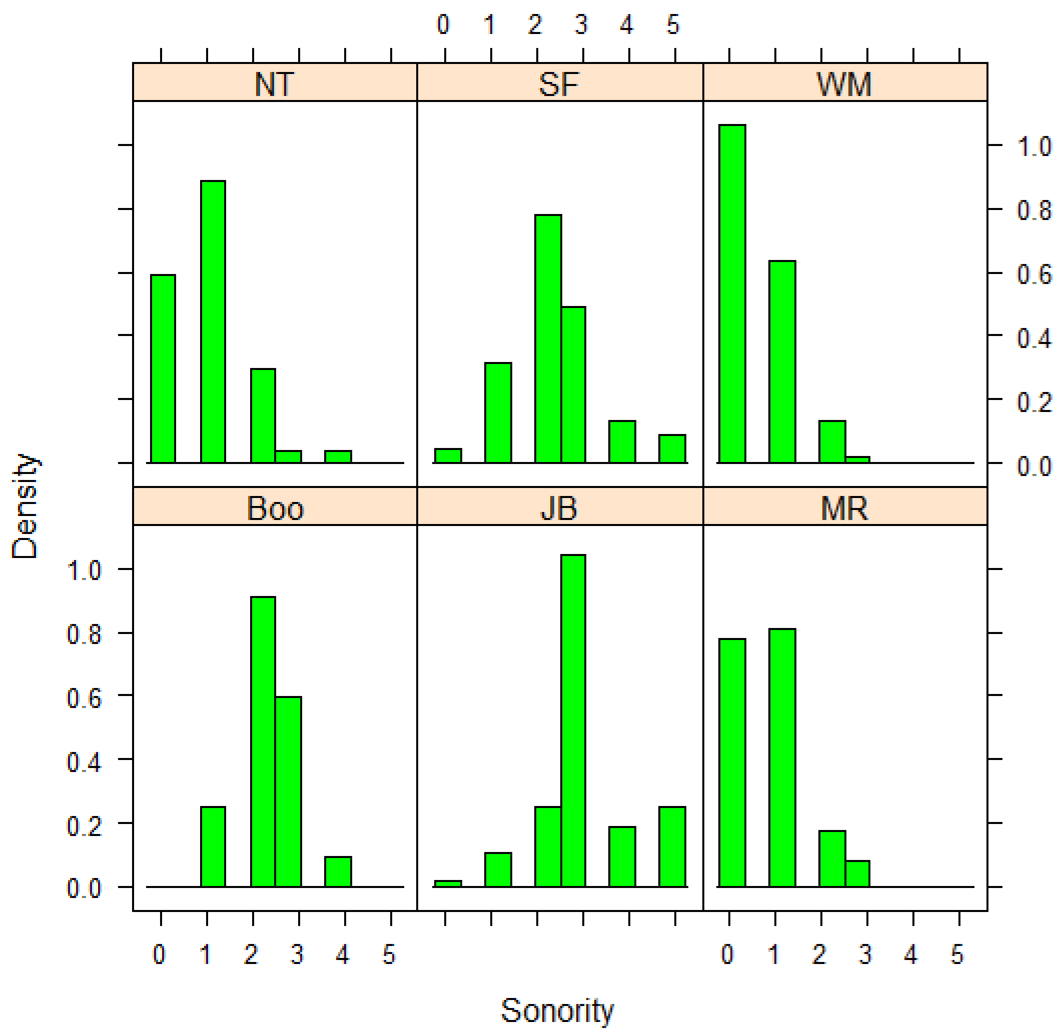


Figure 48. Histograms for sonority values in /g/ by speaker.

5.3.5. Loglinear Models I: Factors

In this section we compare the different measures of contrast precision along each of the relevant parameters for the /g/-/k/ contrast. We rank the speakers in terms of the importance of each correlate based on these measures of contrast precision, investigating to what degree these rankings correspond with the more basic statistical descriptions given above (e.g. proportional difference between means, proportions of preaspirated segments, etc…), and with each other.

Where we see noncorrespondences between these different measurements we try to explain them based on the statistical structure of the categories for each speaker. Although overall the patterns correspond, there is often much discordance between the rankings because the variation between certain speakers can be quite subtle. I limit my scope to discussing the speakers with the worst and best models for a given correlate in the particular rankings on contrast precision. When the rankings of these speakers do not correspond I attempt to explain why this is the case.

5.3.5.1. Consonant Duration

(71) gives the measures of contrast precision for the /g/-/k/ contrast on the consonant duration parameter. (72) gives the rankings of the speakers by measurement.

(71) Measures of contrast precision for /g/ vs. /k/ on consonant duration by speaker.

	Duration Ratios	R^2	τ	Slope	Accuracy
NT	1:1.7	.6401	.6335	.0302	.8786
Boo	1:2.0	.4877	.5709	.0190	.8141
SF	1:1.3	.1194	.3133	.0072	.6826
JB	1:2.2	.7729	.6729	.0295	.9245
WM	1:1.6	.3933	.4832	.0141	.7102
MR	1:1.8	.4801	.5575	.0178	.7956

(72) Rankings of speakers by measure of contrast precision in (71).

	Proportional difference	R^2	τ	Slope	Accuracy
WORST	**SF**	**SF**	**SF**	**SF**	**SF**
	WM	WM	WM	WM	WM
	NT	MR	MR	MR	MR
	MR	Boo	Boo	Boo	Boo
	Boo	NT	NT	**JB**	NT
BEST	**JB**	**JB**	**JB**	**NT**	**JB**

SF was the lowest ranked for the strength of closure duration as a predictor for all the measures of contrast precision. JB was the highest ranked for all the measures of contrast precision except the slope. NT has the sharpest slope. Recall that NT also has smaller standard deviations for her categories on this parameter than JB. NT's standard deviations are 18.3 and 16.5 ms for /g/ and /k/ respectively. JB's standard deviations are 22.9 and 28.2 ms for /g/ and /k/ respectively. Thus we would expect that the category boundary is less sharp around the area where the logit curve is accelerating fastest. The difference in overlap can be seen by comparing the density distributions of JB in figure 49a with those of NT in figure 49b JB's consonant duration category for /k/ in particular trails off into ranges below 50 ms, whereas NT's does not.

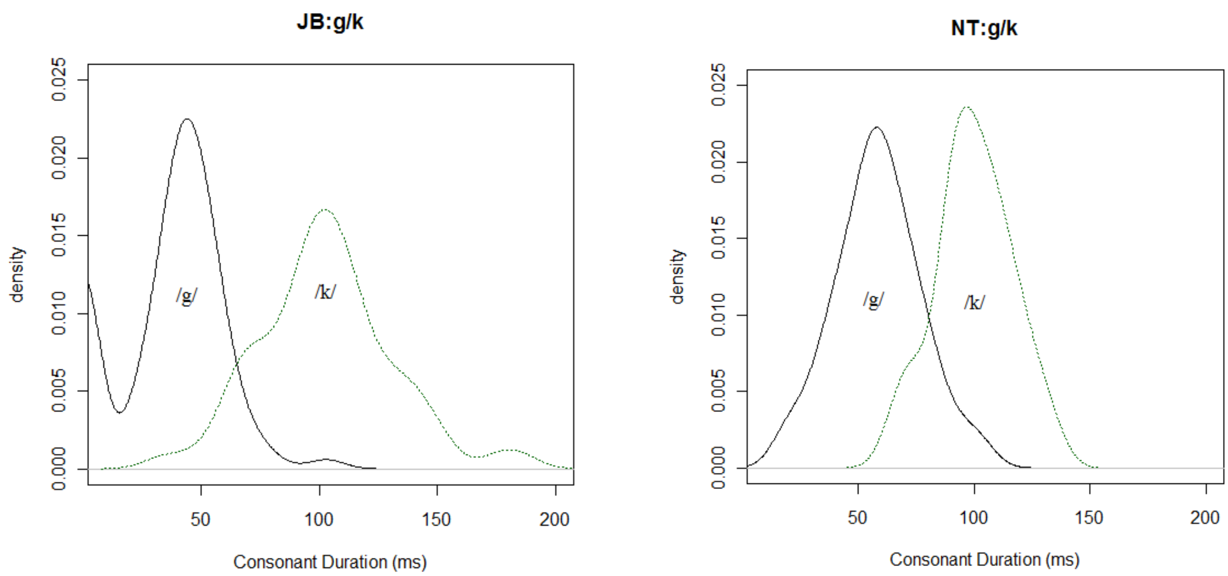


Figure 49a (left). Density distributions for /g/ and /k/ on consonant duration for JB. Figure 49b (left). Density distributions for /g/ and /k/ on consonant duration for NT.

5.3.5.2. Postaspiration

(73) gives the different measures of contrast precision for the /g/-/k/ contrast on the postaspiration parameter. (74) gives the ranking of speakers by measurement. In the chart below difference in proportions refers to the proportion of postaspirated fortis stops minus the proportion of postaspirated lenis stops.

(73) Measures of contrast precision for /g/ vs. /k/ on postaspiration by speaker.

	Difference in proportions	R^2	τ	Slope	Accuracy
NT	.53	.3329	.4605	.0283	.7600
Boo	.93	.7536	.7278	.0277	.8960
SF	.91	.8435	.7875	.0518	.9615
JB	.928	.8183	.8040	.0497	.9565
WM	.77	.2854	.4985	.0256	.7103
MR	.79	.6238	.7229	.0538	.8923

(74) Rankings of speakers by measure of contrast precision in (73).

	Difference in Proportions	R^2	τ	Slope	Accuracy
WORST	**NT**	**WM**	**NT**	**WM**	**NT**
	WM	NT	WM	Boo	WM
	MR	MR	MR	NT	MR
	SF	Boo	Boo	**JB**	Boo
	JB	JB	**SF**	**SF**	JB
BEST	**Boo**	**SF**	**JB**	**MR**	**SF**

The τ and Accuracy measures show that postaspiration for NT has the worst contrast precision. The R^2 and Slope show that WM is the worst on this parameter. NT's τ is larger because NT has the most postaspirated lenis /g/s which means that there is more discordance on this category space overall. WM's R^2 is lower than NT's because his postaspirated fortis stops generally have a smaller duration of mVOT (a mean of 16.2 ms as opposed to NT`s mean of 28.8 ms). Even when stops are postaspirated for WM they are very close to the point of the highest probability of confusion relative to other speakers (Pr(0.5)) which is at 12 ms for WM (it is at 26 ms for NT). This has the effect of making WM's predicted probabilities further away from their corresponding dummy variables.

JB has a slightly better τ coefficient for postaspiration than SF. This corresponds to slight differences in the standard deviations of their categories. JB's standard deviation for /k/ is 1 ms less than that for SF. MR has a higher slope than SF and JB despite only ranking fourth for all the other measurements. MR's postaspirated fortis stops are closer to 0 ms, where the density distribution of the postaspiration for lenis /g/ is the highest. Figure 50 displays the density distributions of postaspiration in fortis /k/ for speakers JB, SF and MR. MR's category is closer to 0 ms making the slope towards Pr(1) steeper as is demonstrated in figure 51.

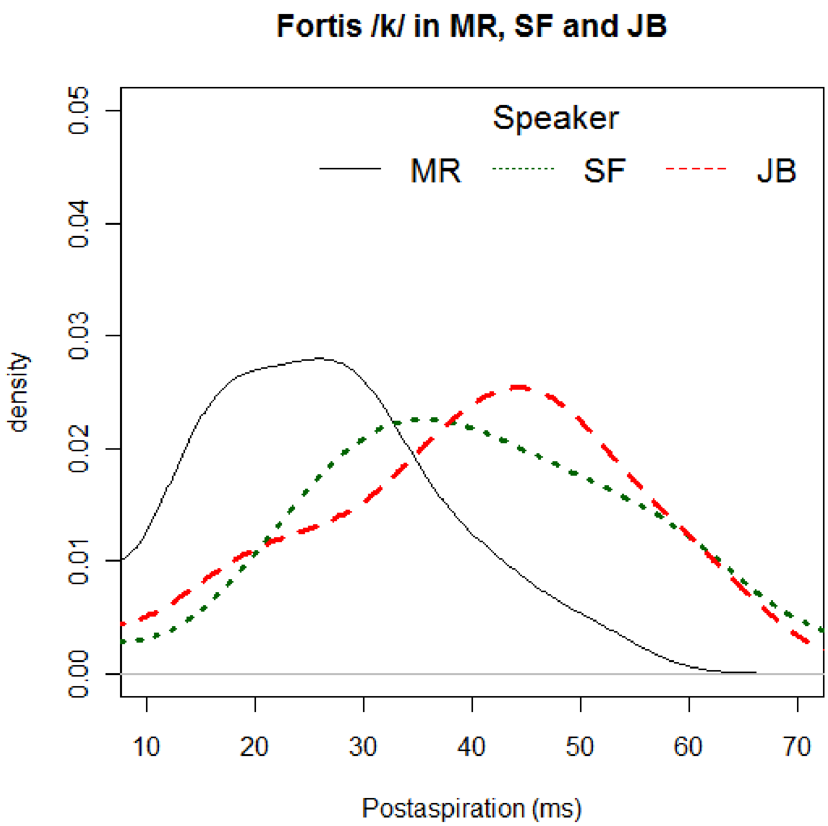


Figure 50. Density distributions for /k/ on postaspiration for MR (solid), SF (dotted) and JB (dashed).

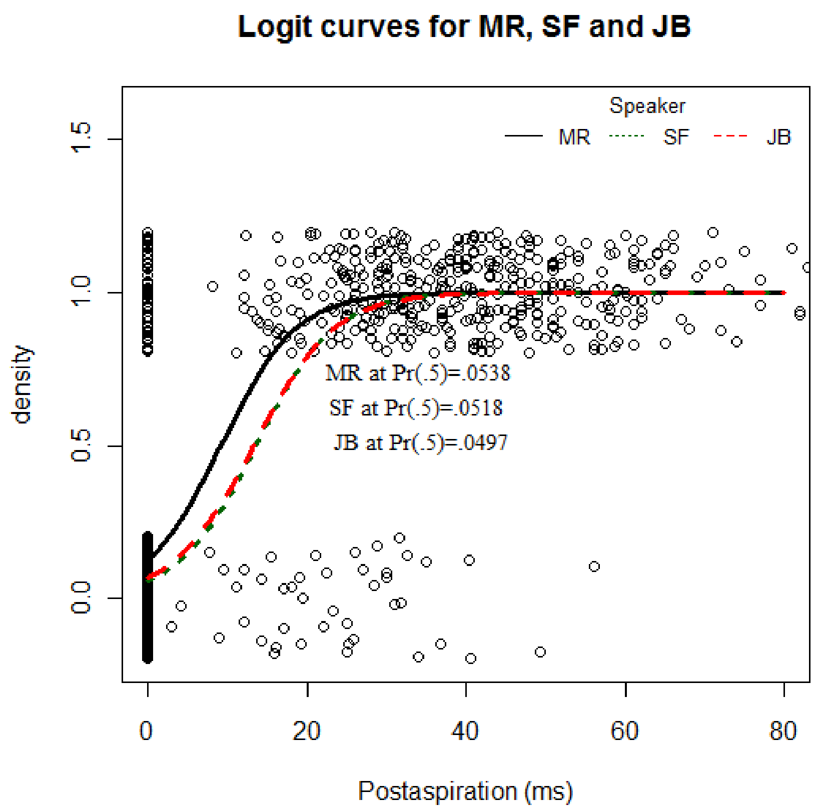


Figure 51. Loglinear cuvres for /g/-/k/ contrast on postaspiration for MR (solid), SF (dotted), and JB (dashed).

5.3.5.3. Preaspiration

(75) gives the measures of contrast precision for velars by speaker. (76) gives the rankings of speaker by measure. In the following chart proportion refers to the proportion of preaspirated fortis /k/s. Lenis /g/s never have preaspiration.

(75) Measures of contrast precision for /g/ vs. /k/ on preaspiration by speaker.

	Proportion	R^2	τ	Slope	Accuracy
NT	.63	.4799	.6539	.0521	.8143
Boo	.69	.4473	.6080	.0462	.8406
SF	.51	.3440	.5527	.0500	.7566
JB	.38	.2499	.4873	.0667	.6894
WM	.80	.7033	.7735	.07135	.9000
MR	.59	.4119	.6130	.0353	.7961

(76) Rankings of speakers by measure of contrast precision in (75).

	Proportions	R^2	τ	Slope	Accuracy
WORST	JB	JB	JB	MR	JB
	SF	SF	SF	Boo	SF
	MR	MR	Boo	SF	MR
	NT	Boo	MR	NT	NT
	Boo	NT	NT	JB	Boo
BEST	WM	WM	WM	WM	WM

JB is ranked the lowest for preaspiration according to all the measures of contrast precision except the slope. JB has a higher slope for preaspiration than one might expect because his preaspiration durations are the shortest overall (mean=12 ms) and thus closer to the density distribution associated with lenis /g/ (which has a mean/median of 0 ms with a standard deviation of 0 ms). WM's contrast precision is the best for preaspiration using all the different measures.

5.3.5.4. Sonority

(77) gives the measures of contrast precision for velar stops on the sonority parameter. (78) ranks the speakers by measurement. Proportion in the following table refers to the proportion of voiceless fortis /k/s to voiceless lenis /g/s. Accuracy is not presented because the data are (quasi-separate). Fortis velar /k/s never have a sonority value above 0.

(77) Measures of sonority for /g/ vs. /k/ on sonority by speaker.

	Proportion	R^2	τ	Slope	Accuracy
NT	.68	.4545	.6375	1.1624	.8100
Boo	1	.9476	.8678	1.79125	1.000
SF	.98	.9407	.8388	1.5455	.9812

JB	.99	.4855	.8023	0.1899	.9662
WM	.43	.2085	.4488	1.0493	.5000
MR	.48	.3500	.5668	1.2669	.7876

(78) Rankings of speakers by measure of contrast precision in (77).

	Proportions	R^2	τ	Slope	Accuracy
WORST	**WM**	**WM**	**WM**	**JB**	**NT**
	MR	MR	MR	**WM**	**WM**
	NT	NT	NT	NT	SF
	SF	JB	JB	MR	MR
	JB	SF	SF	SF	JB
BEST	**Boo**	**Boo**	**Boo**	**Boo**	**Boo**

Sonority is the worst predictor for WM for all the measurements of contrast precision except for slope. JB's logit curve has a shallower slope than WM's. JB's slope is shallow because so many of his tokens have a sonority value of 3. His logit curve becomes shallower because its ceiling effect is reached later in the sonority space. Boo's data for the sonority value display complete- separation. Sonority is the best predictor for this speaker.

5.3.6. Loglinear Models II: Multiple Regression

In this section I use multiple regression to assess the main hypothesis stated in chapter 3, that contrasts between lenis-fortis sets as category systems have close to the same degree of contrast precision. I try to fit the best model for each speaker using the AIC (Burnham & Anderson 2002, Anderson 2008). In each section I start with what I will call "the basic model" which consists of an additive multiple logistic regression model with all of the factors discussed in the previous section. Based on the results of the basic model, nonsignificant factors are removed and suspected interactions are added until the best model is achieved (according to the lowest AIC). I then compare the models for all the speakers and discuss the extent to which the measures of contrast precision corroborate the main thesis. The count of tokens for velar stops by speaker are given in (79).

(79)

	Boo	JB	MR	NT	SF	WM
k	138	66	76	35	76	55
g	120	89	113	50	82	96

5.3.6.1. NT: /g/-/k/

The basic model for NT for the /g/-/k/ contrast is presented in (80). The AIC is 32.65.

(80) Basic model for NT: /g/-/k/

	Estimate	Pr(>|z|)
(Intercept)	-9.8446	0.0029 **
ConsDur	0.0894	0.0065 **
PostAsp	0.0994	0.0338 *
PreAsp	0.0600	0.1511
Sonority	-2.2123	0.1833

When nonsignificant factors were removed the AIC increased to 38.94. When only sonority was removed from the basic model the AIC was 33.78. When only sonority was removed from the basic model the AIC was 34.99. Two-way interaction terms between consonant duration and postaspiration and consonant duration and sonority were significant (p=.0126 and p=.03034 respectively) but neither of these models were better fits to the data in terms of the AIC. Thus the best model is the basic model in (80).

5.3.6.2. Boo: /g/-/k/

The basic model for Boo for the lenis-fortis contrast in velars is given in (81). The AIC is 29.69.

(81) Basic model for Boo: /g/-/k/

	Estimate	Pr(>|z|)	
(Intercept)	1.0273	0.6954	
ConsDur	0.0084	0.6867	
PostAsp	0.0193	0.3940	
PreAsp	0.0843	0.1503	
Sonority	-4.9008	0.0041	**

When nonsignificant terms were removed the AIC decreased to 26.03. This is the best model for Boo. It is given in (82). When consonant duration was readded in a multiplicative model the interaction term between consonant duration and sonority is significant (p=.0027) but the AIC increased to 31.62.

(82) Best model for Boo: /g/-/k

	Estimate	Pr(>|z|)	
(Intercept)	4.0133	3.57e-10	***
Sonority	-7.5038	2.79e-06	***

5.3.6.3. SF:/g/-/k/

The results of the basic model for SF for the /g/-/k/ contrast is produced in (83). The AIC is 19.25.

(83) Basic model for SF: /g/-/k/

Estimate Pr(>|z|)

(Intercept)	-1.1114	0.6684
ConsDur	0.0178	0.5952
PostAsp	0.1178	0.0115 *
PreAsp	0.0403	0.3366
Sonority	-3.2406	0.0233 *

When nonsignificant factors were removed the AIC decreased to 16.04. In the multiplicative version of this model, with just preaspiration and sonority, the interaction term was nonsignificant (p=.976) and the AIC increased to 18.9. Hence the best model is that produced in (84).

(84) Best model for SF: /g/-/k/

	Estimate	Pr(>|z|)
(Intercept)	1.1911	0.2192
PostAsp	0.1181	0.0184 *
Sonority	-4.8571	0.0006 ***

5.3.6.4. JB: /g/-/k/

The results of the basic model for JB for the /g/-/k/ contrast are given in (85). The AIC is 23.6.

(85) Basic model for JB: /g/-/k/

	Estimate	Pr(>|z|)
(Intercept)	0.66786	0.759533
ConsDur	0.04318	0.010338 *
PostAsp	-0.03568	0.358163
PreAsp	0.02238	0.677798
Son	-7.44796	0.000512 ***

When nonsignificant factors were removed the AIC decreased to 20.1. No two way interaction terms came out as significant. The results for the best model are given in (86).

(86) Best model for JB: /g/-/k/

	Estimate	Pr(>|z|)	
(Intercept)	0.1508	0.9196	
ConsDur	0.0402	0.0121	*
Son	-6.6399	5.06e-07	***

5.3.6.5. WM: /g/-/k/

The results for the basic model for WM for the /g/-/k/ contrast are given in (87). The AIC is 32.66.

(87) Basic model for WM: /g/-/k/

	Estimate	Pr(>|z|)	
(Intercept)	-8.6626	1.53e-05	***
ConsDur	0.0649	0.0002	***
PostAsp	0.0836	0.0547	
PreAsp	0.2004	0.0034	**
Sonority	0.1055	0.9379	

When nonsignificant factors were removed the AIC decreased to 32.66. The interaction term on a multiplicative version of the this new model was significant (p=.0020), but the AIC increased to 34.76. The results of the best model according to the AIC are given in (88).

(88) Best model for WM: /g/-/k/

	Estimate	Pr(>|z|)	
(Intercept)	-9.7306	9.24e-06	***
ConsDur	0.0787	0.0001	***
PreAsp	0.3388	0.0006	***

5.3.6.6. MR: /g/-/k/

The results of the basic model for MR for the /g/-/k/ contrast are given in (89). The AIC is 47.92.

(89) Basic model for MR: /g/-/k/

	Estimate	Pr(>|z|)
(Intercept)	-8.8387	3.91e-06 ***
ConsDur	0.0836	3.55e-05 ***
PostAsp	0.1531	0.0001 ***
PreAsp	0.0709	0.0006 ***
Sonority	-1.2464	0.4093

The AIC decreased to 47.20 when nonsignificant factors were removed. A two-way interaction between consonant duration and postaspiration was significant (p=.000348) and improved the model (AIC=45.21). The results from the best model are given in (90).

(90) Best model for MR: /g/-/k/

	Estimate	Pr(>|z|)
(Intercept)	-14.2311	5.61e-06 ***
ConsDur	0.1404	2.27e-05 ***
PostAsp	0.5341	4.29e-05 ***
PreAsp	0.1045	5.49e-05 ***
ConsDur:PostAsp	-0.0044	0.0003 ***

The addition of other two way interactions between preaspiration and any other predictor caused the model to not converge.

5.3.6.7. Summary: Contrast Precision between Complex Categories: /g/-/k/

In this section we compare the speakers in terms of the contrast between /g/ and /k/ as complex categories. An overview of the most important predictors for each speaker is given in (91). The numbers in each of the cells represent the coefficient for the predictor with all the variables standardized (the mean subtracted from the value divided by the standard deviation). Recall we cannot compare the AIC between speakers directly. Each speaker has a different amount of /g/s and /k/s. The AIC value depends on information entropy (i.e. how much information is lost be the model), which is contingent on sample size.

The table in (91) contains coefficients associated with each factor involved in the model with each variable standardized. The coefficients for the predictors represent the values when all of the other predictors are at their mean. The units are also standardized so it is easier to compare their relative importance in a particular speaker's model. However, since the variables do not have all of the same distributional structures (when compared to each other and possibly when compared across speakers) the coefficients do not directly represent the relative importance of each cue in each speaker's model. The mapping of probability functions onto the parametric phonetic space is too contingent on relationships between the parameters and the statistical structure of the density distributions, some of which are highly skewed.

(91) Overview of /g/ vs. /k/ as complex categories.

	ConsDur	PostAsp	PreAsp	Sonority	Interactions
NT	2.413	1.415	1.103	-1.790	
Boo				-8.957	
SF		1.327		-7.871	
JB	1.687			-6.640	
WM	2.735		6.294		
MR	3.210	2.802	2.672		-1.986 (ConsDur:PostAsp)

All of the speakers have different models for the /g/-/k/ contrast based on their production data. One notable difference is the number of dimensions used by the speakers in making the contrast. Despite the fact that Boo encodes other dimensions for /g/ and /k/ (Boo's /k/s are twice as long as his /g/s on consonant duration), a model with only sonority is sufficient for this contrast for him. /g/-/k/ are always distinguished with using voicing in my data. Generally the other speakers rely on more dimensions. This difference between Boo and the other speakers corresponds well to the findings of those phoneticians who have been interested in establishing "invariance" associated phonetic contrast (e.g. Blumstein 1986, Stevens 2002, et al.).[50] One of the recent findings of this research paradigm has been that invariance is present in controlled speech but obliterated in natural speech where "substitute" or "secondary" cues are coopted to mark the relevant contrasts (Stevens & Keyser 2010, cf. Jessen 1998 for definitions of "substitute" and "primary" correlates etc…). The data in (91) could be seen as supporting this picture since Boo's data were all from elicitation and the other speaker's data were from more natural speech.[51] The difference between Boo and most of the other speakers also makes sense from the perspective of H & H theory, which we have already discussed. Boo's speech is closer to the hyperspeech end of the continuum than the speech of other speakers in this study because his data are from elicitation which I assume is closer to clear speech (cf. Moon & Lindblom 1994, Picheny et al. 1986). Acoustic targets are reached more emphatically and consistently, his model can consequently afford to be less complex. The explanation based on invariance and H & H speech has some problems, however, notably that there is very little difference between Boo's model and SF's.

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[50] See the articles in Perkell & Klatt (1986) for issues related to this research paradigm.

[51] However, in most studies on invariance subjects are asked to read a word list using a consistent carrier phrase whereas for Boo the words were taken from more naturalistic sentences. In fact in many cases investigators feel that they need to have subjects produce invented words in order to prove that there is "invariance" associated with a contrast (e.g. Kim et al. 2010).

The different coefficients associated with each correlate suggest that the speakers are using different weightings of these correlates in their speech to mark the /g/-/k/ contrast. The first evidence of this comes from the fact that most of the speakers are using different dimensions in general to mark the contrast in their production. So as with the /d/-/t/ contrast WM uses consonant duration and preaspiration whereas MR uses these dimensions in addition to postaspiration. For the /d/-/t/ contrast WM and MR's models suggested that the former was marking the contrast more strongly based on the two comparable dimensions (consonant duration and preaspiration) but that MR was partly compensating for this by using postaspiration.[52] In this case, however, consonant duration appears to be a better predictor for MR. Figure 52 gives loglinear curves for WM and MR for the /g/-/k/ contrast on consonant duration when all other factors are held at 0. The slope of MR's loglinear curve is steeper than WM's at the highest probability of confusion. In addition to this MR uses postaspiration for making the contrast. 83% of MR's fortis tokens have postaspiration and in these cases the probability of a correctly choosing a fortis token increases drastically. This can be seen from figure 52 which compares the loglinear curves of WM and MR on consonant duration when preaspiration is 0 ms and postaspiration is 30 ms. The fact that the curve ceilings for MR at a very early stage on the consonant duration space with 30 ms of postaspiration indicates that this correlate is extremely useful for marking the contrast irrespective of consonant duration. Postaspiration is not in WM's model for the /g/-/k/ contrast. The reason is because occurrences of postaspiration are predictable from distinctive values of consonant duration or preaspiration.

[52] Partly compensating, because it seems that based on the correlates studied in this investigation MR had a lower contrast precision than WM between /d/ and /t/ according to the Accuracy measure.

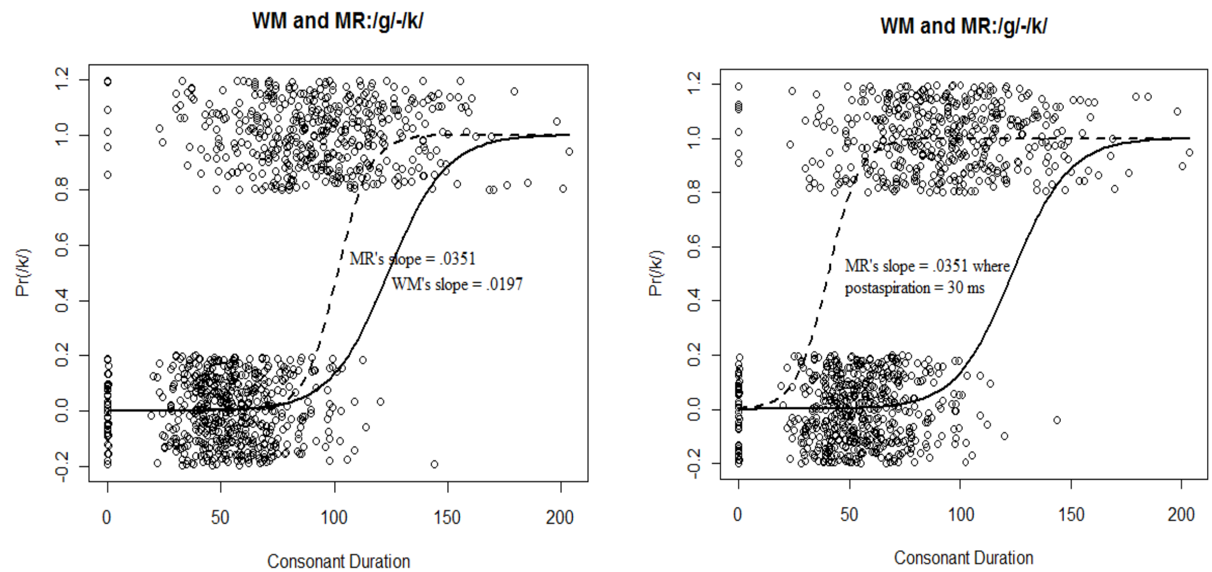

Figure 52a (left). Loglinear curves for /g/-/k/ contrast on consonant duration for WM (solid) and MR (dashed) with all other factors held at 0 ms. Figure 52b (right). Loglinear curves for /g/-/k/ contrast on consonant duration for WM (solid) and MR (dashed) with preaspiration at 0 ms and postaspiration a 30 ms for MR.

When we compare loglinear curves over consonant duration we are describing a gradual increase in the probability of /k/ over /g/. If it is worth it for a speaker to use preaspiration in her model then any token that has preaspiration can instantly be recognized as a fortis stop irrespective of the values on other parameters. Notice that 80% of WM's fortis stops have preaspiration, meaning that the other correlates are essentially only relevant in predicting the other 20%. MR has 59% of her fortis stops preaspirated. The power given to the other correlates in her model might be seen as accounting for that 11% that it cannot predict with preaspiration.[53] Consequently she adds another dimension (postaspiration) and needs consonant duration to be a more consistent predictor. Again, this situation might suggest that the speakers are using a

[53] Of course this is an oversimplification. This angle of description does not take into account that, depending on the speaker, phonetic covariates can have different degrees of multicollinearity with one another. The predictive power we might naively attribute to MR's coefficients does not necessarily take into account that how important they are. If we observe figure 52a, it appears that the probability of a velar stop token being fortis would be close to 1 at approximately 150 ms. The importance of consonant duration in relation to preaspiration really depends on how much this value of consonant duration is associated with no preaspiration. If lower values of consonant duration (say around 120 ms) appeared with no preaspiration it would not matter how good the latter predictor was. This problem is only resolved to a certain extent by standardizing the predictor variables in relation to their mean and standard deviation as is done here.

differential weighting of cues to achieve the same result. However, although it might be approximately correct in the case described above, proportions of preaspirated segments do not automatically translate into the predictive power of this correlate for a particular speaker when we consider contrast between complex categories using loglinear regressions (cf. n52). Furthermore, coefficients do not translate into the importance of a correlate for a model since they are contingent on distributional structure, as our discussions on the noncorrespondence between the slope and other measures of contrast precision have emphasized.

The Accuracy measure of contrast precision for the /g/-/k/ contrast is presented in table (92). This table compares the measures of contrast based on one correlate to those based on all of the correlates together.

(92) Accuracy for /g/-/k/ contrast by speaker (rows) on dimensional or multidimensional space (columns).

	ConsDur	PostAsp	PreAsp	Sonority	Best
NT	.8786	.7600	.8143	.8400	.9614
Boo	.8184	.8960	.8406	1.000	1.000
SF	.6826	.9615	.7566	.9812	.9900
JB	.9245	.9565	.6894	.9662	.9935
WM	.7102	.7103	.9000	.5000	.9763
MR	.7956	.8923	.7961	.7876	.9868
Range	.6826-.9245	.7103-.9615	.6894-.9000	.5000-1.000	.9614-1.0000

In general the data in table (92) corroborates the thesis; that despite the large amount of variation, all speakers mark the /g/-/k/ contrast with a closer degree of contrast precision. There is more variation between the measures at individual parameters than between the measures for the best model by speaker.

6. Discussion and Summary

Research in phonetic typology has shown that languages encode and contrast phonetic categories on a high dimensional phonetic space (Pierrehumbert 2003b). Analogous phonological units are encoded on these phonetic continua in a language specific fashion. This applies to the descriptive label "lenis/fortis" as it is used in the description of phonological inventories across languages. The basic distinction between phonemes transcribed as /b/-/p/, /p/-/pp/ etc., depending on the linguist is actually encoded on a variety of phonetic continua. The relative weight given to each continuum for the purpose of maintaining this contrast is language and even dialect specific.

In this thesis I attempted to formalize Pierrehumbert's concept of category and category system to model the contrast between lenis and fortis stops based on production data from six speakers of Saulteaux Ojibwe. I developed the notion of contrast precision in relation to categories and category systems. Based on the results of loglinear models, various measures of contrast precision were compared. A distinction was made between contrast precision on a particular phonetic continuum or dimension and contrast precision between category systems on a multidimensional phonetic space. A hypothesis was formulated in relation to contrast precision based on findings in phonetic typology (Pierrehumbert 2003b), quoted in (93)

(93) Although speakers/dialects of Saulteaux may vary in terms of how strongly the lenis-fortis contrast is marked on particular dimensions of obstruent space (i.e. they will have different

levels of contrast precision for these dimensions), when the contrast is compared on a k-dimensional space of phonetic correlates, the differences in contrast precision will become increasingly small as k increases.

This hypothesis underscores many issues that are complex and extremely contingent since it is based on relationships between dimensions and the measure of contrast precision employed. It is also based on the size of k, i.e. how many parameters are involved in the comparison. Still, I have had various degrees of success in corroborating the hypothesis in (93) in this thesis. It is worth reviewing why we would expect (93) to be true in the first place.

Oversimplifying for a moment, generally the literature on phonetic typology suggests that an increase in the importance of one dimension of phonetic encoding for contrast maintenance between units of phonetic encoding implies a concomitant decrease in the importance of other dimensions. For example Engstrand & Krull (1994) investigated vowel length in conversational Swedish, Finnish and Estonian. They found that the density distributions of long and short vowels in Swedish overlapped more than for Finnish and Estonian. This could be related to the finding that vowel length distinctions are enhanced by formant structure to a greater extent in Swedish than in the other languages.

A similar situation was found in Korean but between generations rather than across languages. Older speakers of Korean produced large differences in VOT between lenis and aspirated stops (30-35 ms for lenis, 93-108 ms for aspirated). VOT values for these two types did not overlap. F0 also covaried with the contrast but was considered a redundant correlate (Silva 2006), a byproduct of the articulatory configurations used to make the VOT difference. In recent studies with speakers born after 1965, the VOT values overlap more, but the contrast is reinforced by F0 on the vowels following the stops (Kang & Guion 2008). Thus, contrast precision on VOT was reduced and replaced by a higher precision on the F0 dimension. Although there are some complications the current study suggests that speakers that use more voicing on lenis stops (JB and Boo) use less preaspiration. Speakers that use more preaspiration on fortis stops (WM and MR) will tend to mark less lenis stops as voiced. SF seems to use preaspiration and voicing together to mark the contrast, to the detriment of consonant duration compared to this value for other speakers.

These phenomena have functional explanations. On the one hand a certain amount of acoustic distance between sounds must be maintained in order for the contrast to be perceived. On the other hand redundant phonetic attributes are often not maintained in production because they imply an increase in articulatory effort or complexity. (The interplay between these two forces has often been used to explain regularities in the structure of phonological inventories (Lindblom & Maddieson 1986, Boersma 1998).) If we take the example from Korean described above, we can see that the loss of VOT as an important correlate for the lenis-aspirated contrast was a consequence of the latter functional drive (minimal articulatory effort) and the concomitant increase of importance of F0 as a consequence of the former (perceptual distance).

The situation is not as simple as the caricature above would suggest. Redundancies must always exist in the marking of phonetic contrast for change to occur at all (Blevins 2007). Hence, the drive towards minimal articulatory effort is only a factor. Thus we should not expect to find perfect trading relations between cues. This redundancy implies that covariates of phonetic contrast may not be orthogonal. For example, in Korean the F0 was undoubtedly coded by the older speakers, the younger speakers enhanced the importance the feature rather than inventing out of thin air (cf. Kirby 2011, Kang & Guion 2008, 2009). Two auxiliary theories can help explain how this situation comes about; the acoustic theory of speech production and exemplar theory (Pierrehumbert 2000, Pierrehumbert, Beckman & Ladd 2000).

From the acoustic theory of speech production we know that there are nonorthogonalities in the mapping of articulation to acoustic output (Pierrehumbert 2000). For instance a longer voiceless laryngeal gesture generally creates higher intraoral pressure which will tend to produce a longer and more intense aspiration burst after the release (Fant 1960, Stevens 2000). This explains why in a two-way obstruent contrast aspiration is typically associated with longer voiceless consonants. A language that has only a two-way contrast between obstruents will not contrast [d^h] vs. [t:] for example. If aspiration is contrastive it is associated with the longer voiceless set of consonants.

Voicing is another example. Vocal fold vibrations during a stop consonant become increasingly harder to maintain beyond a certain closure duration (Ohala 1983). Thus longer consonant duration will tend to be more voiceless and thus it would be odd for a two way contrast to mark a longer consonant with more glottal vibrations during the closure (e.g. [d:] vs. [t]). Thus, the acoustic theory of speech production explains regularities in the direction that a particular correlate covaries with the lenis-fortis stop. Exemplar theory explains why a speaker would even encode a phonetic feature that might be redundant in the signal. In exemplar theories repeated associations between covariates in production get stored in speech as probabilistic associations between exemplar clouds (Johnson 1997, Pierrehumbert 2003b). These associations function as potential catalysts for phonetic change.

In this thesis I used production data from six Saulteaux speakers of Manitoba to ascertain the best loglinear models of the lenis-fortis contrast. Choosing the best models meant that redundant correlates would be removed from the model. Redundant correlates were those that had minimal significance in terms of predicting the contrast when other potentially more important factors were considered. I also described the covariates by themselves (one dimension at a time) because, although redundant, they represent an important repository for potential phonetic/phonological change and thus need to be documented.[54] The models based on multiple logistic regression can be viewed as the best model a listener would infer based on the production data recorded in my database for each speaker. The best model was chosen based on a trade off between simplicity and fit to the data (i.e. information theoretic multimodel inference (Burnham & Anderson 2002, Anderson 2008)). Analogously, our hypothetical listeners only use those dimensions that they have good reason to believe are functional for marking the contrast. If we assume that our speakers have approximately the same functional drive to maintain the lenis-fortis contrast[55] then our hypothetical listeners should construct models based on their production

[54] If the F0 of the older speakers of Korean had not been documented, redundant as it was, we would lack understanding of the diachronic process that led to the younger speakers using F0 as contrastive.

[55] By "the same functional drive", I mean that it is equally important in communication. This is related to the concept of functional load (Hockett 1967) which gives a metric of how important a contrast is based on the information entropy the loss of that contrast would entail. The idea here is that since the speakers have approximately the same lexicons and the same phonological inventories they should have close to the same functional drive to maintain the contrast. Of course this assumption would not always be legitimate. Western Saulteaux speakers must not have the same drive to maintain the contrast between alveolar and palatal fricatives as other speakers since they are losing this contrast (Valentine 1994).

data with approximately similar degrees of contrast precision whatever the relative weighting of cues in the corpus.

Naturally our models were dependent on sample size. Bilabials may have produced simpler models in general because there was less reason to think weaker or highly collinear correlates were not just random. For velars, however, the models were more complex overall. SF and MR used two dimensions and NT, JB and MR used one dimension. Interestingly for Boo only one dimension was necessary because the measurement for voicing was completely separate. I attributed this to the fact that Boo may have been using clearer speech, because his data were from elicitation.

Although it is obvious that there is much variation between the speakers in terms of the encoding of lenis and fortis stops, when we attempt to model the contrast using multiple regression quantifying the relative weight of the factors involved poses some problems. Standardizing the variables helped to a certain extent but there were still some problems with inter-speaker comparison. For example from the coefficients in table 91 that JB had a higher coefficient for preaspiration than MR. An obvious reason for this might be that MR's preaspiration predictor is collinear (or more collinear) with other predictors. This turned out to not be the case.[56] In fact the reason can be attributed to the difference in the distribution of phonetic values for JB. JB's preaspirated stops were all closer to the density distribution for lenis /g/ on preaspiration. This

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[56] Unfortunately any time an interaction term was added to MR's /g/ vs. /k/ model, the model did not converge. Thus, we could not assess the multicollinearity directly with an interaction term A logistic regression of consonant duration as a predictor variable and a binomial response variable for preaspiration (0=no preaspiration, 1= preaspiration above 0 ms) for MR's /k/s came out as significant with a negative sign (p=.00384). If preaspiration was collinear with consonant duration we would expect the opposite relationship. The same trend was found with postaspiration and sonority for MR.

increased the slope of the loglinear curve without necessarily implying that JB's preaspiration is a better predictor than MR's.

Despite these problems I maintain that the approach taken here and the descriptive facts uncovered by this approach have much to offer Ojibwe dialectology. Investigation of the lenis-fortis contrast in Ojibwe dialects has been limited by the fact that without statistical tools differences between dialects can only be described using statements which assume that phonetic variables such as postaspiration, preaspiration and length are categorical and invariant.[57] For instance, the current study has revealed that there is variation in the amount of fortis consonants that are preaspirated. This variation can be described statistically and in some cases has a fairly straightforward explanation. For example if one compares WM and JB one can see that as WM uses more preaspiration on his fortis stops, JB uses more voicing on his lenis across the POAs. Figure 57 compares preaspiration between WM and JB. Figure 58 shows that most of WM's sonority values for lenis stops fall with 0 indicating that there is very little voicing. Figure 59 reveals that JB has a higher proportion of lenis stops falling in sonority values above 0.

[57] Whether Ojibwe dialectologists actually believe that phonetic interpretation ought to be described this way is besides the point. In some descriptions it is evident that the linguist is aware of the variation. For example Valentine (1994: 124) explains "In many dialects lenis consonants are at least partially voiced in all environments, but fortis consonants are typically both voiceless and more or less geminate."

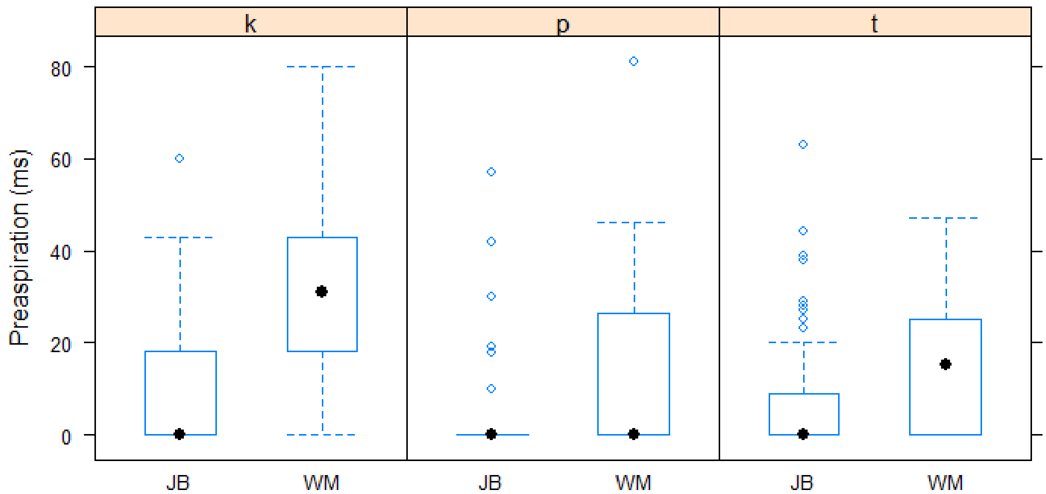

Figure 57. Preaspiration in fortis stops for JB vs. WM by place of articulation.

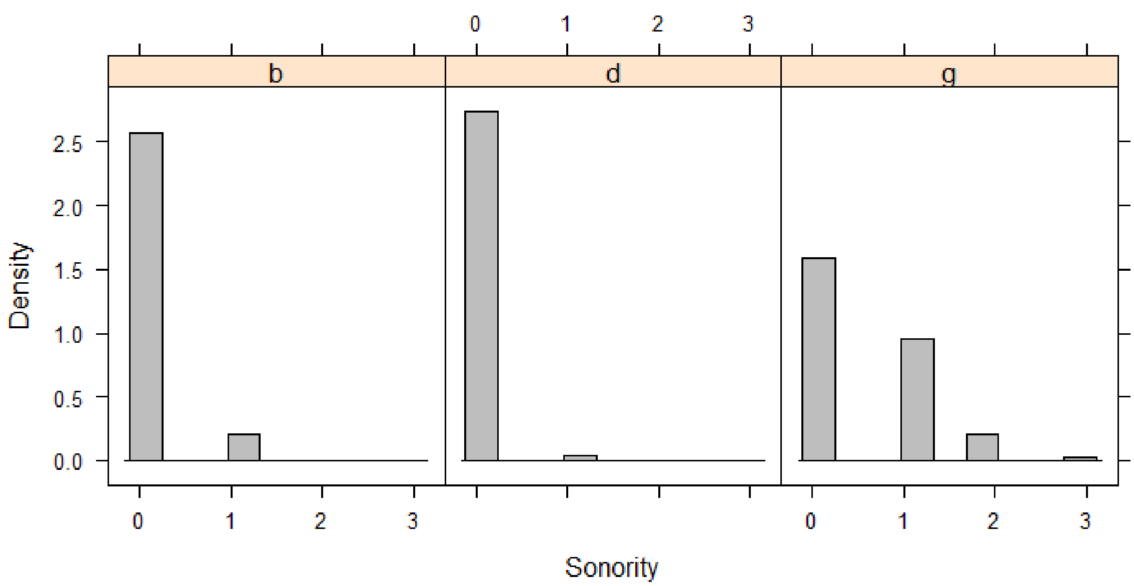

Figure 58. Density of sonority values of lenis stops for WM by place of articulation.

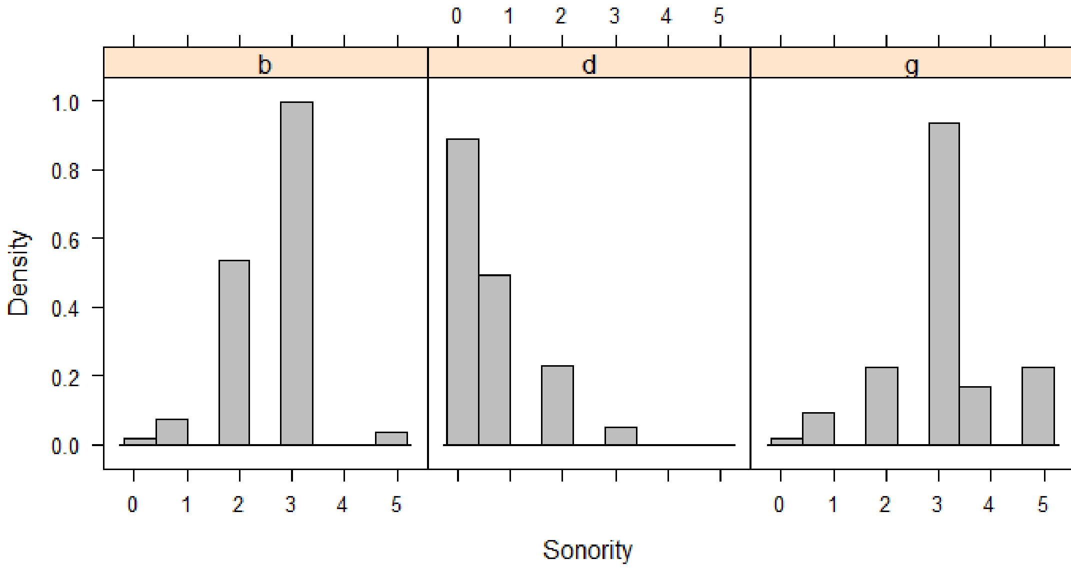

Figure 59. Density of sonority values of lenis stops for JB by place of articulation.

In contrast, previous literature on this topic has been limited to variation that can be described using phonetic transcription. For instance tables (94a) and (94b) were used to describe dialect variation in the realization of obstruents in Rhodes & Todd's (1981) survey of Cree and Ojibwe dialects. (94a) presents the lenis obstruents and (94b) presents the fortis.

(94a) Obstruent Correspondences among Ojibwe Dialects (Rhodes & Todd 1981: 58)

General Ojibwa lenis obstruents not in clusters	p	t	*č*	k	s	*š*
word initial						
Algonquin	/p/	/t/	/č/	/k/	/s/	/š/
other dialects	/b/	/d/	/ǯ/	/g/	/z/	/ž/
word medial, all dialects	/b/	/d/	/ǯ/	/g/	/z/	/ž/
word final						
Ottawa	/p/	/t/	/č/	/k/	/s/	/š/
other dialects	/b/	/d/	/ǯ/	/g/	/z/	/ž/

(94b) Obstruent Correspondences among Ojibwe Dialects

General Ojibwa fortis obstruents	pp	tt	*čč*	kk	ss	*šš*
Algonquin	/p/	/t/	/č/	/k/	/s/	/š/
Severn Ojibwa, northern Northwestern and	/p/	/t/	/č/	/k/	/s/	/š/
Central Ojibwa, and some Saulteaux	[hp]	[ht]	[hč]	[hk]	[s:]	[š:]
other dialects	/p/	/t/	/č/	/k/	/s/	/š/
	[p:]	[t:]	[č:]	[k:]	[s:]	[š:]

With regards to the voiced lenis word medial stops (in my table 94a) Rhodes and Todd (1981: 58) add that they are "sometimes phonetically voiceless in Severn, in the northern Northwestern and Central dialects and in Saulteaux". Thus, they were well aware of the differences in voicing within Saulteaux that this study has investigated. With regards to the preaspiration on fortis stops Rhodes & Todd (1981) state that it occurs for "some Saulteaux" in table 94b. As long as this is not interpreted as meaning that if a subdialect of Saulteaux uses preaspiration they use it on all of their fortis stops it is roughly correct. All the speakers in this study mark preaspiration on some fortis stops for each POA with various degrees of duration.

Despite the fact that Rhodes & Todd's (1982) description of dialect variation is roughly correct it is still an oversimplification. At a deeper subphonemic level there is important variation in the statistical structure of the phonetic correlates of lenis and fortis stops. This probabilistic allophonic variation could be an important aspect in identifying subdialects by community or other sociophonetically marked variables. The phonetic transcription approach to dialect variation is also simply unable to model or understand collinearities or orthogonalities between correlates at all. With multiple loglinear models we can assess to what extent preaspiration trades off with consonant duration in making a contrast or to what extent a difference in closure duration is predictable from voicing. Describing statistical variation in redundant phonetic features also gives us the potential to document phonetic change. The extent to which phonetic change is gradual or discontinuous can only be investigated with adequate descriptions of the statistical distributions of correlates that encode phonemic oppositions (cf. Pierrehumbert 2001a).

The statistical structure of phonetic encoding is complex and difficult to summarize when multiple dimensions are considered at once. General summaries of what this investigation has uncovered about the phonetic encoding of lenis and fortis stops for each speaker are given below.

NT (Peguis): For NT duration ratios between lenis and fortis stops were 1:1.5 for bilabials, 1:1.2 for dental/alveolars, and 1:1.7 for velars. All of these differences were significant. Postaspiration was only a reliable covariate for the lenis-fortis contrast in velars. It occurred on 100% of /k/s and 47% of /g/s. The postaspiration on /k/s was significantly different than that for /g/s. Postaspiration was a nonsignificant predictor for bilabials and dental/alveolars. Preaspiration occurred on 11% of /p/s, 50% of /t/s and 68% of the /k/s. For velars there was a significant difference in terms of the occurrence and quantity of preaspiration governed by the length feature of the previous vowel. Preaspiration durations range from 12-115 ms (not counting fortis stops that have no preaspiration). Sonority values above 1 occurred on 50% of /b/s, 7% of /d/s and 68% of /g/s. The majority of NT's voiced stops had sonority values of 1 (77%). Only /g/ had some tokens above this value. No multiple regression model was constructed for NT's bilabials. For dental/alveolars the best model contained only preaspiration, all other factors being too weak to be considered useful. For velars all of the correlates were used in the best model. Two way interaction terms between consonant duration and postaspiration and consonant duration and sonority were significant; however these did not improve the model. Modelling was generally less effective or informative for NT compared to other speakers due to smaller sample size. From the model with velars consonant duration appears to be the best predictor with other correlates having fairly substantial importance (their coefficients were never less than half of the coefficient for consonant duration for standardized variables).

Boo (Long Plain): For Boo duration ratios between lenis and fortis stops were 1:1.8 for bilabials, 1:1.6 for dental/alveolars, and 1:2 for velars. All of these differences were significant. Postaspiration was a reliable correlate for all of the POAs but was not particularly strong for the /d/-/t/ contrast. Dental/alveolar lenis stops are postaspirated 78% of the time with a mean duration of 11 ms, while the fortis counterpart /t/ is always postaspirated with a mean of 28 ms. Preaspiration occurred on 10% of /p/s, 49% of /t/s and 69% of /k/s. The preaspiration ranges from 8-113 ms. Boo consistently used voicing as a strong correlate for lenis stops. 97% of /b/s, 81% of dentals and 100% of /g/s had sonority values of 0. For Boo, the sample size was the largest and this gave as the possibility to develop the most complex models. However, Boo's speech was most likely hyperarticulated compared to the other speakers in this study. This had the predictable effect of the exageration of certain acoustic cues to the point where the presence of others was not necessary in the speaker's best model. For example, despite the fact that consonant duration, postaspiration and preaspiration were all strong predictors when described individually for the /g/-/k/ contrast only Sonority was necessary in Boo's final model, because it displayed complete separation. All the other predictors became superfluous. For Boo voicing was the strongest predictor in every case. For dentals consonant duration, postaspiration and preaspiration could be seen as playing a part in the contrast because a significant amount of /d/s were voiceless (19%). Still, sonority was the strongest predictor. It would be interesting to see to what extent this situation would hold in conversational speech (i.e. hypospeech).

SF (Brokenhead): For SF consonant duration ratios were 1:1.6 for bilabials, 1:1.3 for dental/alveolars, and 1:1.3 for velars. In the latter case the ratio is slightly larger if we include syncopated velar /g/s (1:1.4). These differences were significant. Postaspiration was a significant predictor for all the POAs, but for dental/alveolars the difference is not very large. /p/ has postaspiration 100% of the time, its lenis counterpart 6% of the time. /k/ has postaspiration 95% of the time, its lenis counterpart 4% of the time. However while /t/ has postaspiration 100% with a mean duration of 30 ms of the time its lenis counterpart is postaspirated 86% of the time with a mean duration of 22 ms. Thus postaspiration is a weaker predictor for the /d/-/t/ contrast. In the multiple logistic regression model with the POAs pooled the interaction between dental/alveolar place was negative and almost as large as effect of postaspiration on predicting the /b/-/p/ contrast. Preaspiration occurred on 5% of /p/s, 27% of /t/s and 51% of /k/s. The range in duration of preaspirated fortis stops was 10-93 ms. 96% of /b/s, 65% of /d/s and 98% of /g/s had sonority values above 0. For bilabials, no model was constructed because I could only find 25 fortis /p/s. In the multiple loglinear regression for the /d/-/t/ contrast voicing seems to be the best predictor although consonant duration postaspiration and preaspiration all have minor effects. With the coefficients based on standardized variables it the largest and when the correlate is taken alone it has the highest Accuracy score. For the /g/-/k/ postaspiration and sonority were chosen as the predictors. The sonority value coefficient is much stronger again (7.9 for sonority compared to

1.3 for postaspiration). Thus for SF voicing seems to be the best predictor in each case with postaspiration secondary. Overall SF uses the most postaspiration out of all the speakers to make the lenis-fortis contrast.

JB (Sandy Bay): For JB consonant duration ratios between lenis and fortis stops were 1:2.1 for bilabials, 1:1.7 for dental/alveolars, 2:2.2 for velars. In the case of velars the ratio increases to 1:2.9 if all the syncopated /g/s are counted. Postaspiration was a significant predictor for the bilabial and velar contrasts. Postaspiration on /p/s occurs 74% of the time, on /k/s 94% of the time and only 1% of the time of these consonant's corresponding lenis stops. For alveolar/dental stops, however, postaspiration was not a significant predictor. While /t/s are postaspirated 98% of the time with a mean of 25 ms, /d/s are postaspirated 78% of the time with a mean of 22 ms, a small difference. Preaspiration occurs on 14% of /p/s, 26% of /t/s and 38% of /k/s. The range in duration of preaspiration on fortis stops for JB is 9-63 ms. Voicing is a strong predictor of the lenis-fortis contrast. Sonority values above 0 occur on 99% of /b/s, 46% of /d/s and 99% of /g/s. Overall voicing seems to be the strongest predictor. It is the only factor in JB's model for the /b/-/p/ contrast. For velars both consonant duration and sonority are in the best model but sonority is clearly more important. Its coefficient is larger (6.64 compared to 1.69 for consonant duration) and its accuracy measurement is stronger when we compare the factors by themselves (.97 for sonority, .92 for consonant duration). Consonant duration is still a strong predictor, but most of its ability to predict the contrast can be subsumed under the voicing difference. For dental/alveolars voicing becomes less important as dental/alveolar /d/ is only voiced 46% of the time. In the best model for the /d/-/t/ contrast consonant duration was a better predictor by coefficient (2.3>1.9) and Accuracy measure when considered alone (.84>.50). Thus, voicing appears to be the best correlate for JB but dental/alveolar /d/ is voiceless too often for it to be as strong a predictor for alveolar/dentals.

WM (Lake St. Martin): For WM consonant duration ratios between lenis and fortis stops are 1:1.4 for bilabials, 1:1.3 for dentals, 1:1.6 for velars. Postaspiration was a significant predictor for bilabials and velars but not for alveolars. For bilabials there was significantly less postaspiration than for other speakers. Only 35% of /p/s were postaspirated compared to 83% of /k/s. All /t/s had some postaspiration but this was not a covariate of contrast for dental/alveolars because 95% of /d/s had it as well. Preaspiration occurred on 43% of /p/s, 56% of /t/s and 80% of /k/s. The range of duration of WM's preaspirated stops is 12-148 ms. Voicing is not important for WM. Only 8% of /b/s and 2% of /d/s have sonority values above 0. 57% of /g/s have a sonority value above 0, but this is largely predictable from consonant duration.[58] In WM's model for the /b/-/p/ contrast consonant duration, postaspiration and preaspiration all improve the model. Preaspiration has the strongest coefficient when the variables are standardized. For the /d/-/t/ model only consonant duration and preaspiration are included. Again preaspiration seems to be the most important predictor. Its coefficient is higher (3.8>1.9) when the variables are standardized. The Accuracy score for preaspiration is higher than consonant duration's as well when the dimensions are analyzed separately (.77>.69). For the /g/-/k/ model consonant duration and preaspiration are the predictors again with preaspiration as the stronger predictor. Generally for WM preaspiration and higher consonant duration values trade off to mark fortis consonants, with the former tending to play a more important role. Further evidence that they trade off comes from the fact that they are negatively correlated with each other for fortis stops ($p<.0001$, R^2 =

[58] A linear regression with consonant duration as the response variable and sonority as the predictor variable for /g/s comes out as significant ($p<.0001$), with an adjusted R^2 of .234 and a slope of -14.7.

.112). Overall the pattern in WM's speech is that where nondistinctive consonant durations of fortis stops are produced these are supplemented with more preaspiration.

MR (Fairford): For MR consonant duration ratios between lenis and fortis stops are 1:1.95 for bilabials, 1:1.4 for dental/alveolars, and 1:1.75 for velars. All of these differences were significant. Postaspiration was a significant predictor for the lenis fortis contrast in all of the POAs. Postaspiration occurred on 31% of /p/s (mean: 6 ms), 94% of /t/s (mean 13 ms) and 83% of /k/s (mean 22 ms). In the case of alveolar/dentals and velars postaspiration was negligible of the lenis counterpart. It occurred on 73% of /d/s with a mean only 3 ms less than that for /t/. Voicing was a slightly better predictor of the lenis-fortis contrast for MR than for WM. 51% of /b/s, 14% of /d/s and 42% of /g/s had sonority values over 0. Still like WM, models for the lenis fortis contrast by POA were better without sonority as a predictor. MR's best model for the /g/-/k/ contrast only contained consonant duration. For dental/alveolars preaspiration became much more important as the distance between /d/ and /t/ on consonant duration is smaller. Lenis /d/ is longer for all speakers compared to the other lenis stops. Postaspiration and preaspiration were thus included in the model. Preaspiration was the most important both in terms of its coefficient from standardized variables (3.7> 1.5 (ConsDur), .6 (PostAsp)) and its Accuracy measure when the dimensions were considered separately (.74>.66 (ConsDur), .45 (PostAsp)). For velars consonant duration was an important correlate as well, however on its own postaspiration had a higher Accuracy measure (.89>.80). A two way interaction term between consonant duration and postaspiration revealed that these terms were collinear and thus a certain amount of the postaspiration was redundantly marking the contrast. The interaction term between preaspiration and consonant duration was nonsignificant. Furthermore these predictors trade off each other just as with WM. More ambiguous consonant durations imply a higher probability of preaspiration. Evidence for this comes from the fact that consonant duration and preaspiration as negatively correlated with each other ($p<.0001$, $R^2 = .203$). Thus postaspiration predicts the contrast but could be considered less important because it is collinear with consonant duration. Consonant duration and preaspiration trade off with one another in MR's /g/-/k/ contrast.

Investigation of the acoustic correlates and the relationship between the phonetic dimensions of the lenis-fortis contrast across these six speakers has revealed that there is much subdialectal variation in the Saulteaux of Manitoba. The variation is not random, however. It is governed on the one hand by the need to maintain contrast and on the other by sociophonetic dimensions. If the strength of one correlate for a particular phonemic contrast diminishes, the contrast needs to be reinforced by another correlate for it to be maintained. This serves as a constraint on the variation in the phonetic encoding of complex categories. Sociophonetic dimensions on the other hand act to maintain the variation between dimensions. Differences in pronunciation are important sociolinguistic variables and index different social categories within a speech community (Foulkes & Docherty 2006). Any linguist or anthropologist who has ever worked with an Ojibwe speaker for a substantial amount of time has undoubtedly been told by their consultant that he or she is able to tell the community where a particular interlocutor is from by their speech (at least within a reasonable geographical range). The next step in this project, apart from documenting more correlates, would be to identify the sociolinguistic variables that are conditioning the ubiquitous phonetic variation described in this study.

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