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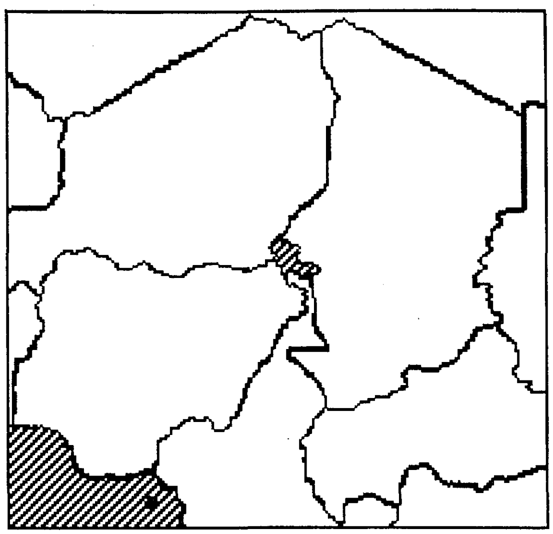
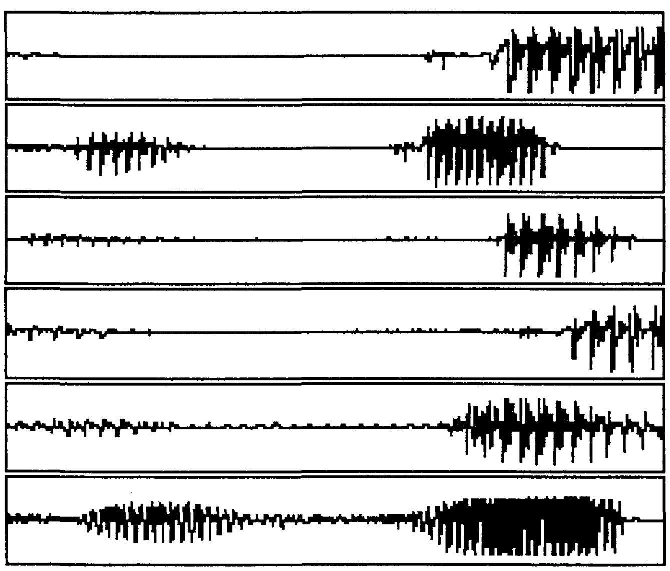


Investigating Laryngeal Contrasts:

An Acoustic Study of the Consonants of Musey



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ABSTRACT OF THE DISSERTATION

Investigating Laryngeal Contrasts:

An Acoustic Study of the Consonants of Musey

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Aaron Michael Shryock

Doctor of Philosophy in Linguistics

University of California, Los Angeles, 1995

Professor Russell G. Schuh, Co-chair

Professor Ian Maddieson, Co-chair

In the study of the production of voiceless consonants, previous attention has been given primarily to differences in the timing and magnitude of glottal abduction and adduction gestures. This dissertation demonstrates that these parameters are not necessarily utilized contrastively in the production of distinctive voiceless consonants. In Musey, a Chadic language spoken in northern Cameroon and southwestern Chad, there are two series of voiceless obstruents and two h's which contrast in word-initial position. A multifaceted examination of the acoustic properties of these consonants indicates that they do not differ in timing or magnitude of glottal abduction gestures. Rather, the acoustic properties of these consonants indicate that they differ in longitudinal vocal fold tension. There is also strong motivation for positing a distinction at the segmental level in the regulation of subglottal pressure.

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Finally, I thank God not only for the life I have received but also for His continued graciousness and mercy.

GI DEPPA

Fok jewe an gi dep coco maŋ Lona. An gam dep ŋgol kay nam ɦan votta kay a an biirigi gi dep manda. An gam dep cocoo kay buu manna halaŋ nam njun unu, nam njununu buuna ŋgolo varagi may. Ngoo dagani an gagi deb agi banyanna. An gi dep maŋ Mulna vi Polge Lawan may, Pasteur Kepna Paul may, Karsisna Samuel may, Djupduuna Joel may, Jean Akerdena Kassamsou may, agi gor senna suu Polgena halaŋ halaŋ. An gi dep maŋ Pasteur Robert Duncanson may, Pasteur Hamtangou Mark may, Pasteur Samdoukŋa Salomon may, Kaygama Yakub may, agi gor senna suu Gayana halaŋ halaŋ. An min agi gi dep suu magisina lay. Gi dep manda vatwa. Ko Lona ɦaygi votta a ŋgaf taygiya buu ma daŋ tuwa. Lona gagi heppa kagi halaŋ kay sem sa daŋgi, kay sem gorom ma dewna, Yesu Kristu. Amen. An ni Aaron.

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Chapter 1: Introduction

1.1. Introduction

In Musey, a Chadic language spoken in northern Cameroon and southwestern Chad, there are two series of voiceless obstruents and two h's which contrast in word-initial position. A multifaceted examination of the acoustic properties of these consonants indicates that they do not differ along the phonetic parameters generally observed in voiceless consonants. In previous studies of the production of voiceless consonants, attention has been given primarily to differences in the timing and magnitude of glottal abduction and adduction gestures. This study demonstrates that these parameters are not necessarily utilized contrastively in the production of distinctive voiceless obstruents. Rather, these voiceless obstruents differ in longitudinal vocal fold tension. Moreover, it is generally assumed that subglottal pressure cannot be utilized in the production of segmental contrasts. However, the acoustic properties of these consonants suggest that these two series of consonants differ in subglottal pressure as well.

The dissertation is organized as follows. In the next section of this chapter, the phonetic background on phonation and devoicing mechansims and the role of subglottal pressure in consonant production are considered. Then general information on Musey is presented and the phonology and tonology of the language are examined. Not only are there lexical contrasts but these two series of consonants also influence the tonal pattern of the word. This discussion provides the principal phonological evidence for the existence of the subtle phonetic contrast which is the focus of this dissertation. The chapter ends with an examination of the historical development of the contrast. The second chapter presents the procedure used in an acoustic experiment which examines the phonetic basis of the contrast. The results of a qualitative study of voicing are presented in the third chapter. The fourth chapter presents the results of an examination of the temporal properties of the contrasting consonants and adjacent vowels. The spectral properties of these consonants and the adjacent vowels are then investigated and the results presented in the fifth chapter. The sixth chapter discusses these findings and the inferences which can be drawn regarding the phonetic basis of the contrast in Musey as well as the implications of this study for phonetic theory.

1.2. Phonetic background

1.2.1. Phonation and mechanisms for devoicing

Before proceeding to a discussion of Musey, it would be helpful to review what is known generally about phonation and devoicing mechanisms in speech. The vocal folds vibrate when specific physiological and aerodynamic conditions are met in the vocal tract (van den Berg 1958, Stevens 1977, Titze 1980, 1986). The vocal folds must be positioned in a slightly adducted position. The longitudinal tension of the folds must be adjusted within an appropriate range. A transglottal flow of air is also required. The necessary transglottal flow results from a difference between the subglottal and intraoral air pressures. When these conditions are satisfied, the variation in pressure and the movement of the vocal folds which result produce phonation.

The conditions necessary for phonation are actively manipulated in speech in the production of voicelessness. Vocal fold abduction is a commonly employed mechanism in the production of voiceless consonants. The abduction gesture is usually produced in combination with a supralaryngeal constriction which facilitates the cessation of voicing by decreasing the transglottal airflow. In the case of voiceless stops, the constriction in the supralaryngeal cavity impedes the flow of air and the intraoral air pressure rapidly increases. Voicing ceases as the intraoral air pressure rises to the level of the subglottal pressure and the distance between the vocal folds increases.

As noted above, the longitudinal tension of the vocal folds must be adjusted within a given range to satisfy the conditions for vocal fold vibration. Active adjustment of longitudinal vocal fold tension might be expected to be another devoicing mechanism. Halle and Stevens (1971) provide theoretical arguments for the use of increased longitudinal tension as a devoicing mechanism. However, the experimental results in the literature are conflicting. The production of increased longitudinal vocal fold tension and its use as a devoicing mechanism will be considered in depth in Chapter 6.

1.2.2. Subglottal pressure

There is a large body of literature indicating that the respiratory system generates a generally uniform background level of pressure during speech (Ladefoged 1963, 1967, 1968; Lieberman 1967, Ohala 1990). Variation in subglottal pressure associated with the production of specific consonants can generally be explained by either laryngeal or supralaryngeal resistance rather than requiring an assumption of a short-term increase in activity of the chest muscles (Ladefoged 1963, 1967, 1968; Netsell 1969, Löfqvist 1975, Ohala 1990). Short-term increases in subglottal pressure are produced, however, by the respiratory system in emphatically stressed syllables (Ladefoged 1963, 1967, 1968; Lieberman 1967, Leanderson et al. 1987, Sundberg et al. 1993). Although greater subglottal pressure has been reported to occur during the production of the aspirated stops of Korean (Kim 1965, Lee and Smith 1972) and has been inferred to occur in the production of the Korean 'fortis' stops (Dart 1987), it is generally assumed that subglottal pressure cannot be utilized in the production of segmental contrasts. The principal argument for this position is the slow response time of the respiratory system (Ohala 1990). These issues are discussed in more depth in Chapter 6.

1.3. The Musey language

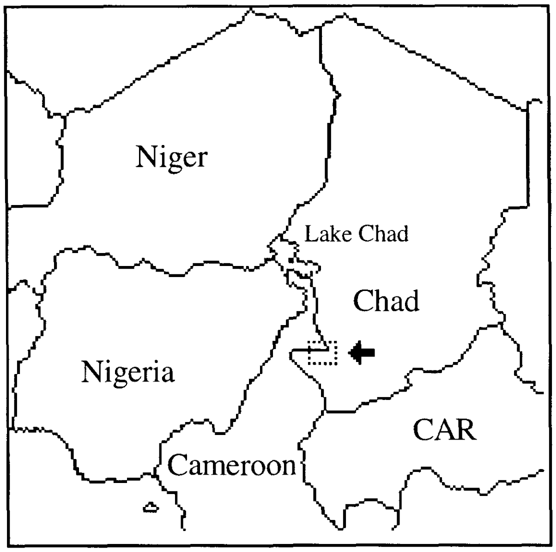
1.3.1. The language and people

There are approximately 150,000 speakers of Musey (R. Duncanson 1992, p.c.). Approximately 120,000 of these speakers live in southwestern Chad in the Gounou Gaya and Fianga sous-prefectures of the Mayo-Kebbi prefecture situated between Fianga and Kelo. The remaining 30,000 speakers live in a geographically contiguous region of northern Cameroon in the Mayo-Danay Division of the Far North Province as seen in the map in Figure 1.1.

1.3.2. Language classification

Musey is one of the languages comprising the Masa group of Chadic languages (Newman 1977b, 1992). The languages comprising the group are subclassified into two groups, the 'northern' and 'southern' groups (Barreteau 1987, Shryock 1990, Tourneux 1990). The northern group consists of Masa, Musey, Marba, and Monogoy. The Marba and Monogoy are culturally distinct groups, but linguistically they may be similar enough to warrant being classified as dialects of a single language (R. Duncanson, 1994, p.c.; S. Lazicki, 1994, p.c.). The southern group consists of Zime (also referred to as Mesme), Peve (also referred to as Zime or Lame), Heɗe (also referred to as Kaɗo), and Ngiɗe (Jungraithmayr 1978, Hufnagel 1986, Noss 1990). The Heɗe and Ngiɗe are similar enough to be classified as dialects of a single language; however, the two groups consider themselves culturally and linguistically distinct (Noss 1990). Zumaya has only a few remaining speakers (Barreteau 1987); its subclassification in the group is unclear.

Figure 1.1. The Musey speaking area of Cameroon and Chad.



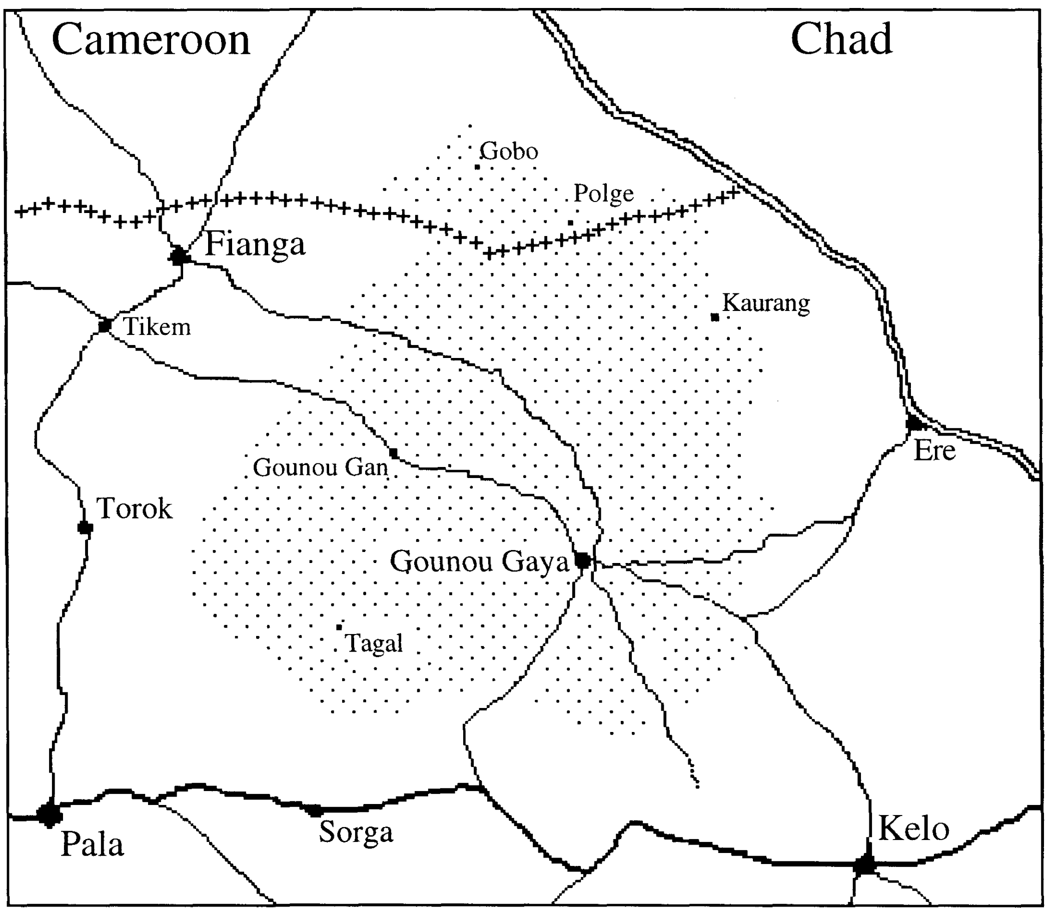
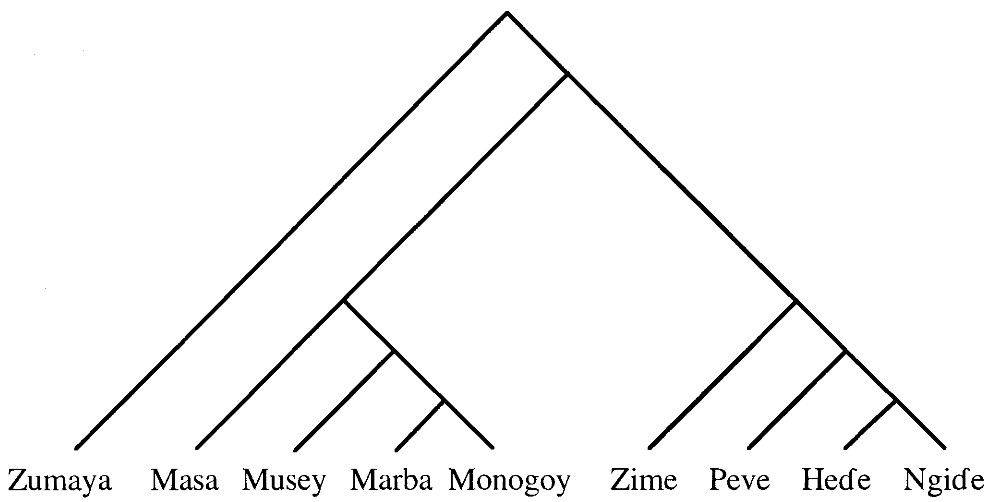


Figure 1.2. The Masa group of languages.



The position of the Masa group in the Chadic family is a controversial issue. Chadic is composed of three major branches: West Chadic, Biu-Mandara or Central Chadic, and East Chadic (Newman 1977a, 1977b; Jungraithmayr and Shimizu 1978). It has been traditionally held that the Masa group of languages has a close genetic relationship to Musgu (Westermann and Bryan 1952, Meyer-Bahlberg 1972; Newman 1977a, Jungraithmayr and Shimizu 1978, Barreteau 1987) and, consequently, is a member of the Central Chadic branch of the family. Newman (1977b) argues against this subclassification and proposes that the Masa group be classified as a separate, fourth branch of the Chadic family. Shryock (1990) provides further evidence for the independence of the Masa group by demonstrating that several sound changes and lexical innovations characteristic of the languages of the Central Chadic branch are not attested for the Masa group of langauges. Barreteau (1987) and Tourneux (1990), however, present arguments based on lexico-statistic findings in support of the traditional classification of the Masa group as a unit within Central Chadic. The position of these languages in the Chadic family remains to be resolved.

1.3.3. Musey Phonology

The Musey consonantal inventory is presented in Table 1.1. (Fédry and Fourier ca 1970; Duncanson 1972; Shryock 1993). A striking aspect of Musey phonology and phonetics is the role played by the two consonant series labelled 'Class A' and 'Class B' in Table 1.1. The first of these sets consists of the segments [p, t, tʃ, k, f, s, ɬ, h]. The set labelled class B is represented by the symbols for the voiced conterparts of these segments. This choice of symbols must not be taken as indicating that the class B consonants are phonetically voiced. Both series of obstruents are phonetically voiceless. The class A [h] and class B [ɦ] tend to be phonetically voiced. In addition to these two classes, there are two implosives and a series of prenasalized stops. The sonorant inventory includes nasals, liquids, and glides as outlined below in Table 1.1.

Duncanson (1972) describes both the class A and class B obstruents as voiceless but does not clarify the phonetic nature of their contrast. Fédry and Fourier (ca 1970) also describe both classes as voiceless; they refer to the two classes as 'tense' and 'lax', respectively. Platiel (1968), however, describes the two classes of obstruents as 'voiceless' and 'voiced'.

Table 1.1. Musey consonantal inventory.

Class A	p	t		tʃ	k	
Class B	b	d		dʒ	g	
	ɓ	ɗ				
	mb	nd		ndʒ	ŋg	
Class A	f	s	ɬ			h
Class B	v	z	ɮ			ɦ
	m	n			ŋ	
		l				
	w	ɾ		y		

All of the consonants in Table 1.1. occur and contrast with each other in word-initial position with the exception of [ɾ] and [ŋ]. Intervocalically, the stop inventory consists of [ɓ, ɗ, g] and the fricative inventory of [v, z, ɮ]. Obstruents are generally voiced in this position; however, there is phonetic variation in degree of voicing with some tokens of the fricatives exhibiting partial or even complete voicelessness. In coda position there are three voiceless, unreleased stops, [p, t, k], and the voiceless fricatives [f, s, ɬ]. The class A [h] and class B [ɦ] occur only in word-initial position. The complete set of sonorants occurs intervocalically as well as in coda position. There are five vowels [i, e, a, o, u].

In Musey there are three level tones, high, mid, and low; and six contour tones, as illustrated in Table 1.2.

Table 1.2. The tone patterns of Musey.

High	tʃó 'evil', túmús 'hair', ɗúmúɾúk 'circular grass mat'
Mid	kōy 'guest', māyāw 'bile', tōgōlōm 'flute'
Low	và 'thing', dèl 'throat', bùzùr 'blood', gòlòŋòt 'knee'
High-Low	sáỳ 'tea', dàŋgáỳ 'prison', kúùzí 'cucumber'
High-Mid	gún̄ 'tree'
Mid-High	wāý 'sibling', ōó 'grace'
Mid-Low	sūm̀ 'bear', lāỳ 'bird', wāỳ 'argument'
Low-High	zèẃ 'rope', dòý 'water jar'
Low-Mid	ndàr̄ 'neighbor', mbàȳ 'maternal aunt'

In Musey the initial consonant of a word influences the tone pattern of the word. Shryock (1993) provides an in depth analysis of the interaction of consonants and tone in Musey. It is important to briefly summarize the manner in which consonants interact with tone because it provides evidence for the phonological significance of the distinction between the class A and class B consonants.

The consonants divide into two groups, 'High' and 'Low' (Duncanson 1972), on the basis of the consonants' influence on the tone pattern of a word when occurring in initial position. The class A consonants together with the laryngealized stops, nasals, liquids, and glides form the High group of consonants. The Low group consists of the class B consonants and the prenasalized stops as seen in Table 1.3.

Table 1.3. The High and Low consonant groups.

High group

p	t		tʃ	k	
ɓ	ɗ				
f	s	ɬ			h
m	n				
w	l		y		

Low group

b	d		dʒ	g	
mb	nd		ndʒ	ŋg	
v	z	ɮ			ɦ

There are two distinct ways in which the initial consonant of a word influences its tone pattern, as discussed in Shryock (1993). First, the initial consonant of a word triggers the assignment of a tone to a word in the case that no tone is associated to the initial tone-bearing unit of a stem. The tone-bearing unit in Musey is the mora. In nominal stems, lexical tones are associated from right to left. Consequently, if the number of tone-bearing units exceed the number of lexical tones, the initial tone-bearing unit(s) of the word do not receive a tone. In the absence of a lexical tone, a word-initial High consonants trigger the assignment of a mid tone to the initial tone-bearing unit. Low consonants trigger the assignment of a low tone. For instance, after the association of a lexical low tone (L) to the rightmost tone-bearing unit of the stem, the initial tone-bearing unit is assigned a tone according to the group of the initial consonant as seen in Figure 1.3.

Figure 1.3. Nominal stems with lexical low melody.

	Lexical melody		Tone assignment		
	L | kuluf		ML | | kuluf		
High group	kuluf	-->	kuluf	-->	[kūlùf] 'fish'
	L | buzur		L | \\ buzur		
Low group	bu zur	-->	buzur	-->	[bùzùr] 'blood'

The initial consonants of verb stems also influence the tone pattern of the verb. In the verbal system, tone has a grammatical function. The tone pattern of a verb indicates the tense/aspect of the verb. The initial consonant of a verbal stem influences the assignment of grammatical tone through the composition of the verb sets. Verbs are grouped into two sets. The verbs with an initial consonant from the High group of consonants are referred to as High verbs; verbs with an initial consonant from the Low group of consonants are Low verbs. The tone patterns of these two sets of verbs in the imperfective and perfective are presented below in Table 1.4. High verbs exhibit a high tone on the first tone-bearing unit of the stem in the imperfective; Low verbs exhibit a mid tone on the first tone-bearing unit of the stem. In the perfective High verbs exhibit a mid tone on the first tone-bearing unit of the stem; Low verbs exhibit a high tone on the first tone-bearing unit of the stem. In both sets of verbs, the tone-bearing units of syllables to the right of the initial syllable receive a mid tone.

Table 1.4. Perfective and imperfective for High and Low sets.

		High set		Low set	
Imperfective					
a.	CV	tó	'sweep'	dō	'pick off'
b.	CVC	kál	'enter'	zāl	'wash grain'
c.	CVCVC	hórōk	'farm'	vārāk	'replace'
Perfective					
d.	CV	tō	'sweep'	dó	'pick off'
e.	CVC	kāl	'enter'	zál	'wash grain'
f.	CVCVC	hōrōk	'farm'	várāk	'replace'

The second manner in which consonants influence the tone pattern of a word involves the rightward displacement of low tones. A word initial consonant of the High group of consonants triggers delinking of a low tone associated to the initial tone-bearing unit of a word if the low tone is associated to more than one tone-bearing unit. Figure 1.4. shows nominal stems with an associated lexical low tone. With cliticization of the enclitic /na/, the low tone spreads rightward. The stem [sà] 'person' has an initial consonant of the High class; consequently, the low tone is delinked from the stem. The stem subsequently surfaces with a mid tone as the result of rules of default mid assignment (DM). The low tone of the stem [fiù] 'goat' is not delinked since the initial consonant is a member of the Low group of consonants.

Figure 1.4. Rightward displacement of lexical low tone.

```
                          LD              DM

               L               L          M  L
               |               |          |  |
High class     sa    -->   sa na   -->   sa na    [ sā+nà ] 'person'

               L           L
               |           | \
Low class      fiu   -->   fiu na                 [ fiù+nà ] 'goat'
```

Rightward displacement also affects grammatical tones. In the subjunctive, a low tone associates to the first tone-bearing unit of the stem in both verb sets. A stem comprised of a single tone-bearing unit surfaces with a low tone as seen in Figure 1.5.

Figure 1.5. Subjunctive.

```
                 L
                 |
High class       to     -->     [ tò ] 'sweep'

                 L
                 |
Low class        do     -->     [ dò ] 'pick'
```

With the affixation of the pronomial suffix /m/ 'him/her', the grammatical low tone spreads rightward due to Low Displacement (LD) as in Figure 1.5. The stem [to] 'sweep' has an initial consonant of the High group; consequently, the low tone is delinked. The stem then surfaces with a mid tone through default tone assignment (DM). The low tone of the stem [do] 'pick' is not delinked since the initial consonant is a member of the Low group of consonants.

Figure 1.6. Subjunctive with affixation.

```
                               LD              DM

                 L             L               M  L
                 |             |               |  |
High class       to     -->    to m     -->    to  m      [ tō+m̀ ] 'sweep it'

                 L             L
                 |             | \
Low class        do     -->    do m                       [ dò+m̀ ] 'pick it'
```

This overview of Musey tonology summarizes the manner in which the initial consonant of a word influences the tone pattern of a word. It is noteworthy that the class A and class B consonants are distinguished by their effect on tone, with the Class A consonants belonging to the High group of consonants and the class B consonants to the Low group of consonants. However, there are minimal contrasts in tone such as seen in Table 1.4. and Figure 1.5. which indicate that the initial contrast between Class A and Class B consonants is independent of the tonal contrast and cannot be predicted from it.

1.3.4. Origin of the class A and class B consonants

The comparative evidence indicates that the contrast between the class A and class B consonants originated from a voicing contrast. As outlined in section 1.3.2., there are two principal subgroups within the Masa group. Musey is a member of the northern subgroup along with Masa, Marba, and Monogoy. Masa exhibits a laryngeal contrast in the obstruents and h's which Caitucoli (1982, 1983) describes as 'tense' and 'lax'. The contrasting consonants in Masa may be similar phonetically to Musey. The phonetic characteristics of the obstruents in Marba and Monogoy are not known. In contrast to Musey and Masa, there is a voicing contrast reported for Zime (Kieschke 1990), Heɗe (Sachnine 1982; Court 1985), and Peve (Venberg 1975, Cooper 1984) which belong to the southern subgroup within the Masa group. The contrast in Peve involves phonetic voicing (R. Venberg 1992, p.c.). The phonetic basis of the reported voicing contrasts in the other languages has not been determined; it is assumed, though, that they involve a phonetic contrast in voicing as in Peve.

The class A consonants of Musey correspond to the voiceless consonants of Heɗe and Zime; similarly, the class B stops correspond to the voiced consonants of these languages. These correspondences are illustrated in Table 1.5. for the alveolar stops.

Table 1.5. Correspondences for the alveolar stops of the Masa languages and reconstructions for Proto-Masa Group (PMG).

	PMG	Musey	Masa	Heɗe	Zime
*t	*ti 'eat'	ti	ti	ti	ti
	*toʔom 'brains'	totoʔon	toɗon	teʔem	toʔom
	*tir 'moon'	til	til	ter	ter
*d	*dif 'flute'	dif	dif	duf	duf
	*duk 'liver'	duk	duk	uduk	aduk
	*der 'throat'	del	del	dɨrai	der

The class A consonants of Musey and the voiceless consonants of Heɗe and Zime correspond to the voiceless consonants reconstructed for Proto-Chadic; the class B consonants and the voiced consonants of Heɗe and Zime correspond to the voiced consonants reconstructed for Proto-Chadic. The reconstructions for Proto-Chadic are based on Newman (1977b) and Jungraithmayr and Shimizu (1978). These correspondences are illustrated for the velar stops in Table 1.6.

Table 1.6. Correspondences for the velar stops of the Masa languages and reconstructions for Proto-Masa Group (PMG) and Proto-Chadic (PC).

	PC	PMG	Musey	Heɗe	Zime
*k	*kɨrfi 'fish'	*kirfi	kuluf	kerfe	kifeʔe
	*ka 'with'	*ka		ka	ka
	*kusɨm 'mouse, rat'	*kɨlɨm	kolom		kɨliŋ
*g	*gʸaɬe 'belch'	*giɬ	giɬ	giɬ	giɬ
	*gʷam 'ten'	*guɓ		guɓ	guɓ
	*gɨfu 'knee'	*gif	gif	gif	guf

Thus, the Masa group of languages inherited the voicing contrast of Proto-Chadic. The historical development which led to the contrast between the class A and class B consonants in Musey apparently involved the loss of a more robust contrast, i.e. voicing, for a phonetically subtle contrast. However, the phonological contrast was not lost. The purpose of this dissertation is to determine the phonetic outcome of this historical development in Musey.

Chapter 2: Procedure

2.1. Introduction

As noted in the preceding chapter, there are two series of voiceless obstruents and two h's which contrast in word-initial position in Musey. These two series of consonants are referred to as 'class A' and 'class B'. Despite the phonological significance of these two classes, the phonetic basis of the contrast between these classes remains unclear. In order to determine the phonetic basis of this contrast, an experiment was designed to investigate the acoustic properties of the class A and class B consonants. This chapter presents the experimental procedure.

2.2. Experimental design and data

The data for this study were collected from eight native speakers of Musey, four males (JO, AK, EF, TA) and four females (AV, EL, PA, BE) while conducting fieldwork in Cameroon in 1992. The male speakers were educated in French which they spoke with varying degrees of proficiency. The female speakers were monolingual speakers of Musey.

A word list of thirty two /C_1VC_2/ tokens was compiled with the assistance of two research assistants who were native speakers of Musey. /C_1/ ranged over the sixteen consonants comprising the class A and class B consonants. It was not possible to find /CVC/ tokens exhibiting the relevant phonological contrasts in onset position with a uniform consonant in coda position. Thus, /C_2/ ranged over the consonants [t, k, s].

The /C_1VC_2/ tokens were all verbs. As noted earlier, aspectual information is indicated by alternations in the tone patterns of the verb stem. The verbs of the High set exhibit a high tone in the imperfective and a mid tone in the perfective; the Low set verbs, on the other hand, exhibit a mid tone in the imperfective and a high tone in the perfective. As a result, the use of /CVC/ verbs enabled the collection of tokens exhibiting the relevant segmental contrasts as well as alternations in tone. The /V/ of the /C_1VC_2/ tokens was thus either [á] or [ā]. The word list is presented in Table 2.1.

Table 2.1. Word list.

a. High set

Imperfective	Perfective	Gloss
pás	pās	'iron'
t+át	t+āt	'eat+her'
tʃák	tʃāk	'pound'
kák	kāk	'sit'
fát	fāt	'finish'
sát	sāt	'rub'
ɬ+át	ɬ+āt	'lift+her'
hát	hāt	'learn'

b. Low set

Imperfective	Perfective	Gloss
bās	bás	'spend'
d+āt	d+át	'tell+her'
dʒāk	dʒák	'place'
g+āk	g+ák	'throw+you (feminine)'
v+āt	v+át	'find+her'
z+āt	z+át	'cut+her'
ɮ+āt	ɮ+át	'extend+her'
ɦ+āt	ɦ+át	'give+her'

Half of the /C_1VC_2/ tokens were bimorphemic, consisting of a /Ci/ stem and a pronominal suffix of the shape /VC/. These /Ci/ stems are realized as [C+aC] with suffixation.

The tokens were placed in the carrier phrase [àzí C_1VC_2 tʃótʃóō] 'they C_1VC_2 a lot'. The speakers were instructed to repeat each token in the carrier phrase in a casual style. The speakers repeated the phrase fifteen times, pausing after each set of five repetitions. The first and fifth repetitions from each set were not included in the data set. Thus, there were 9 repetitions of 32 words produced by 8 speakers resulting in a total of 2304 tokens. The speakers were recorded in a variety of field environments using a Sony WM-D6C tape recorder with a Shure SM10A head-mounted microphone.

2.3. Data analysis

The recorded speech was digitized at a sampling rate of 20 kHz using the Kay Elemetrics Computer Speech Laboratory (CSL) package at the UCLA Phonetics Laboratory. The acoustic data were subjected to three separate analyses. The first analysis involved determining the presence and degree of voicing for the two classes of consonants. The data were subsequently subjected to an analysis of the temporal properties of these consonants and the adjacent vowels. Finally, the spectral properties of the class A and class B consonants and adjacent vowels were investigated.

The data were analyzed with a three-factor analysis of variance (ANOVA) testing for the significant effects of consonant class, place of articulation, and speaker identity on the acoustic properties of the class A and class B consonants and the adjacent vowels under investigation. The main effects of consonant class are discussed in the following chapters. There are significant main effects of place of articulation and interactions between consonant class and place for most of the statistical analyses reported below. Separate two-factor ANOVA's were performed for each place of articulation with the factors consonant class and speaker identity to determine whether the effect of consonant class was significant for each place of articulation. Post-hoc comparisons of means were also conducted with the Spjotvoll and Stoline test (Spjotvoll and Stoline 1973). Significant main effects of speaker identity and significant interactions with the other factors occur in most of the analyses reported below. The effect of speaker identity is discussed when it indicates a difference in production strategy. In the majority of cases, though, the variance is the result of differences in individual baseline values or in the magnitude of a uniform effect. Inter-speaker differences of these kinds are not discussed.

Chapter 3: Qualitative investigation of voicing

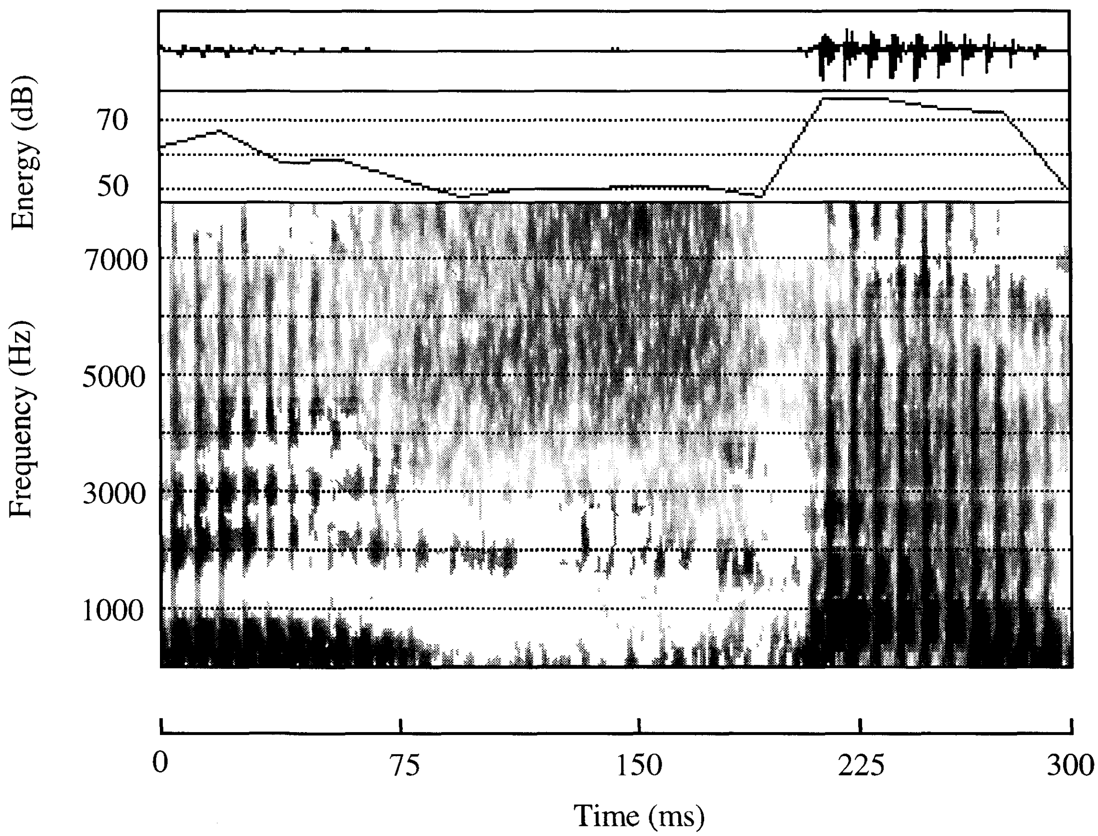
3.1. Introduction

As noted in the first chapter, the contrast between the class A and class B consonants has been described as a contrast in voicing (e.g. Platiel 1968). There is comparative evidence indicating that the class A and class B obstruents correspond to voiceless and voiced obstruents, respectively, in related languages. However, both classes of obstruents have also been reported to be voiceless (e.g. Duncanson 1972). Thus, the data were first investigated to determine whether the class A and class B consonants differ with respect to such voicing.

3.2. Procedure

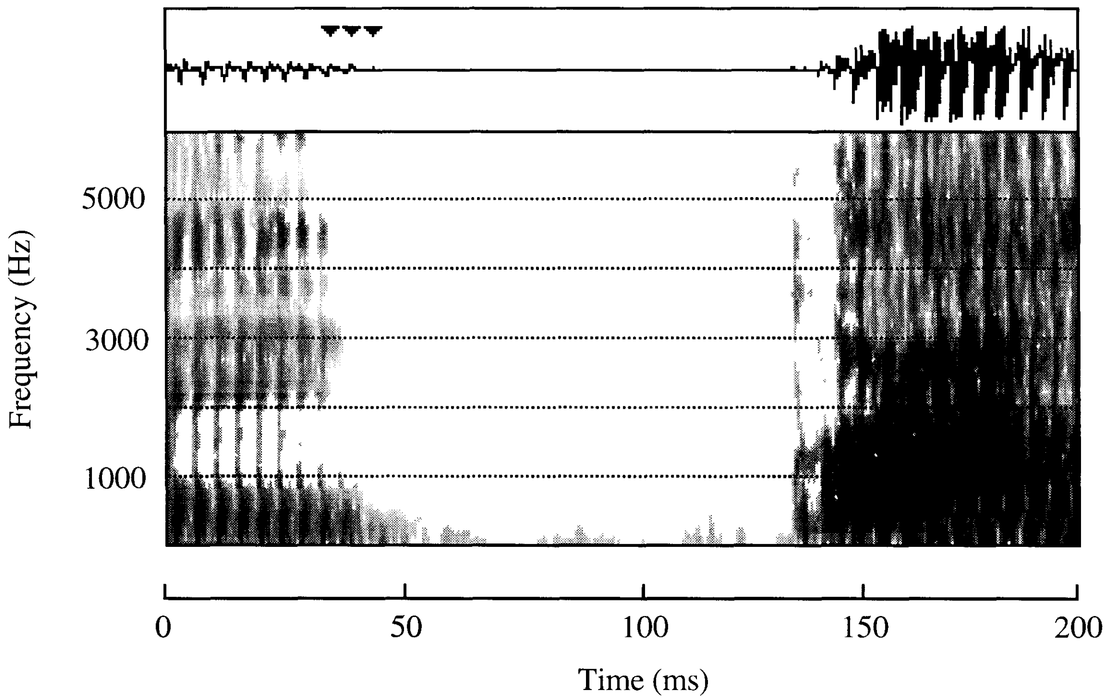
The class A and class B consonants were examined by referring to a wideband spectrogram (bandwidth of 586 Hz) with simultaneously displayed, time-aligned waveform and energy displays. An example of these time-aligned displays is shown in Figure 3.1.

Figure 3.1. Example of time-aligned waveform, energy, and wideband spectrogram displays.



The stops and affricates were classified as either 'voiceless', 'partially voiced', or 'voiced' according to the presence and duration of voicing during the consonant closure. Stops and affricates with fewer than four periods of voicing at the onset of the closure and no subsequent voicing during the closure were classified as 'voiceless'. The criterion of three periods of voicing was chosen because it was found that the stops and affricates exhibited a minimum of two or three periods of voicing. Those with four or more periods of voicing at the onset of closure were considered 'partially voiced'. The onset of the closure was identified as the point at which the formant structure of the preceding vowel ceases. Finally, stops and affricates with voicing through the entire closure were classified as 'voiced'. These three cases are exemplified in Figures 3.2-4.

Figure 3.2. Example of a voiceless class B [b] with three periods of voicing at the onset of the closure designated in the waveform display by markers.



The class A and class B fricatives and the class A [h] and class B [ɦ] were classified in a similar manner as voiceless, partially voiced, and voiced on the basis of the perseverence of voicing into the consonant. The onset of the fricative was identified by the onset of frication and the dissipation of the formant structure of the preceding vowel. The onset of the class A [h] and class B [ɦ] was difficult to determine. However, this indeterminacy in segmentation did not present an obstacle for the classification of these tokens because the majority of the tokens of [h] and [ɦ] exhibit full voicing. Moreover, the cases of partial voicing exhibit sustained voicing at the onset of the [h] and [ɦ] well beyond the four periods of voicing required for classification as partially voiced.

A substantial number of the class A and class B fricatives as well as the class A [h] and class B [ɦ] exhibit one or more periods of voicing which are not contiguous with the preceding or following vowel. The maximum amplitude of the voicing for these periods of voicing was measured in the time-aligned energy display. In the cases in which the difference in the maximum amplitude of the voicing in the consonant and the maximum amplitude of the voicing at the onset of the following vowel was greater than 24 dB, the voicing was disregarded on the assumption that it was some other kind of quasi-periodic sound. In the case that it were, in fact, voicing, it would be too subtle to be perceived. In the cases in which the difference was less than 24 dB, the consonant was classified as exhibiting 'intermittent' voicing. A voiceless class A [s] with no intermittent voicing is shown in Figure 3.5. An instance of a class A [s] with intermittent voicing appears in Figure 3.6.

Figure 3.3. Example of a partially voiced class B [b] with five periods of voicing at the onset of the closure designated in the waveform display by markers.

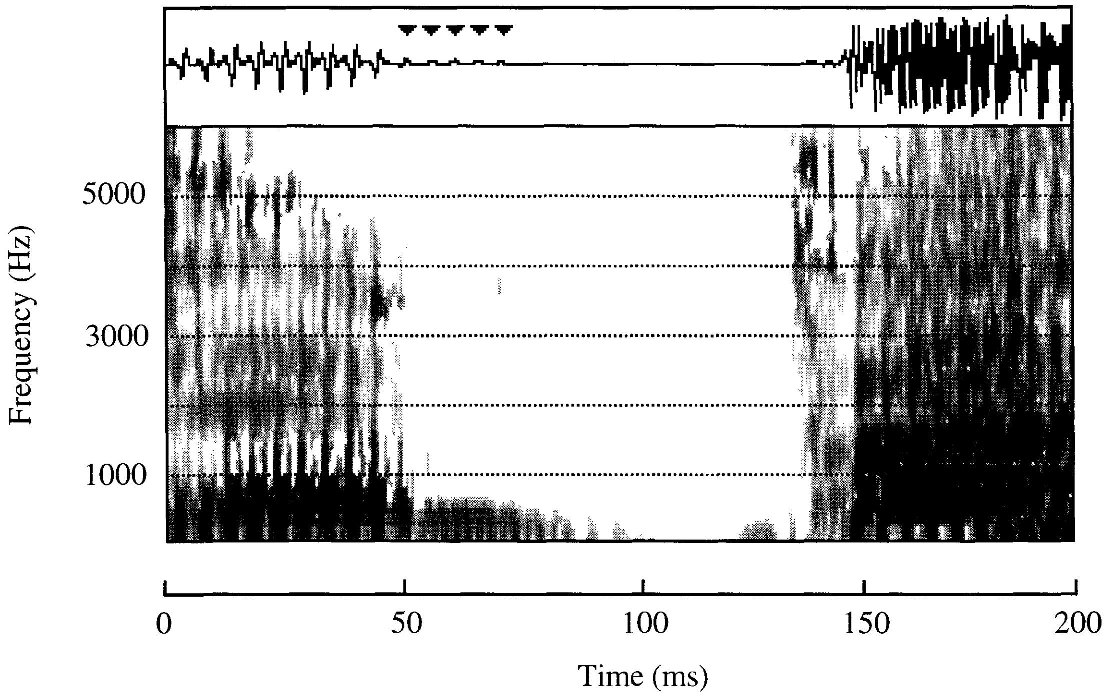


Figure 3.4. Example of voiced class B [b].

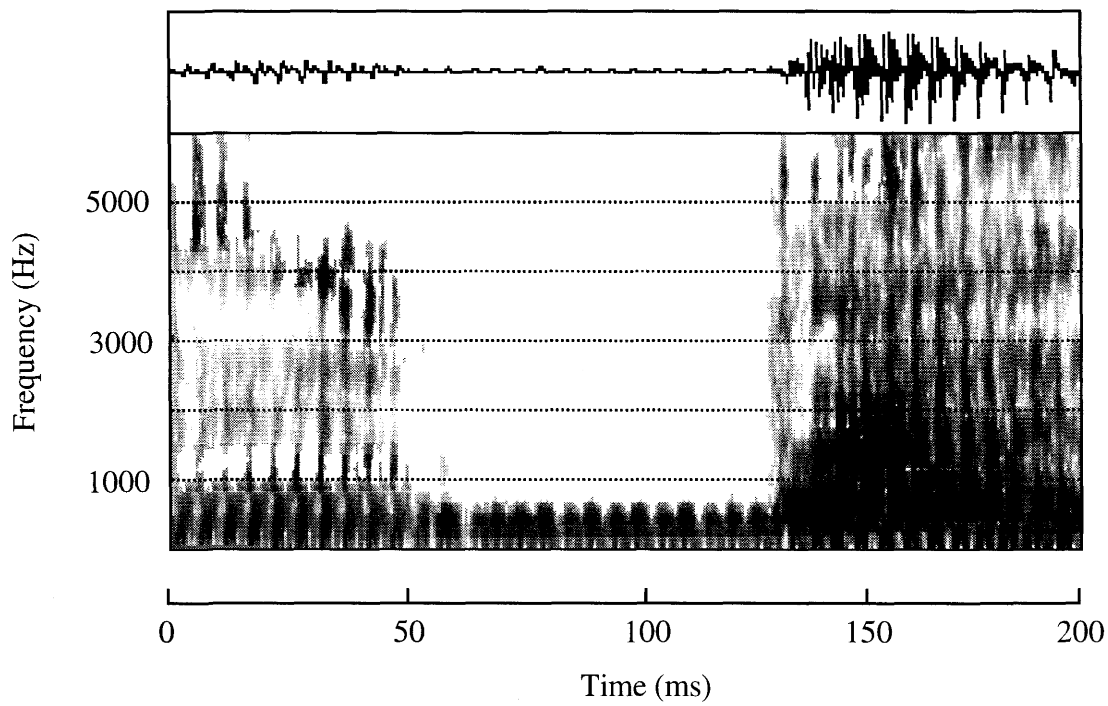


Figure 3.5. Example of voiceless class A [s] with no intermittent voicing during the interval of frication.

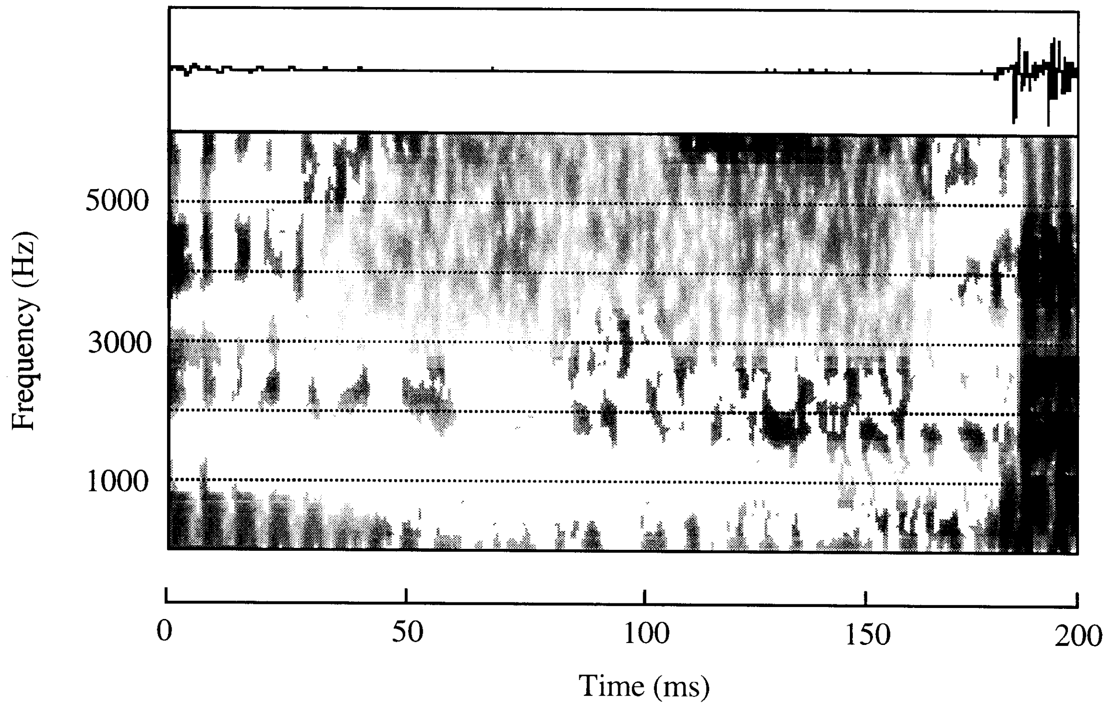


Figure 3.6. Example of intermittent voicing for class A [s] with seven contiguous periods of voicing during the interval of frication designated in the waveform display by markers.

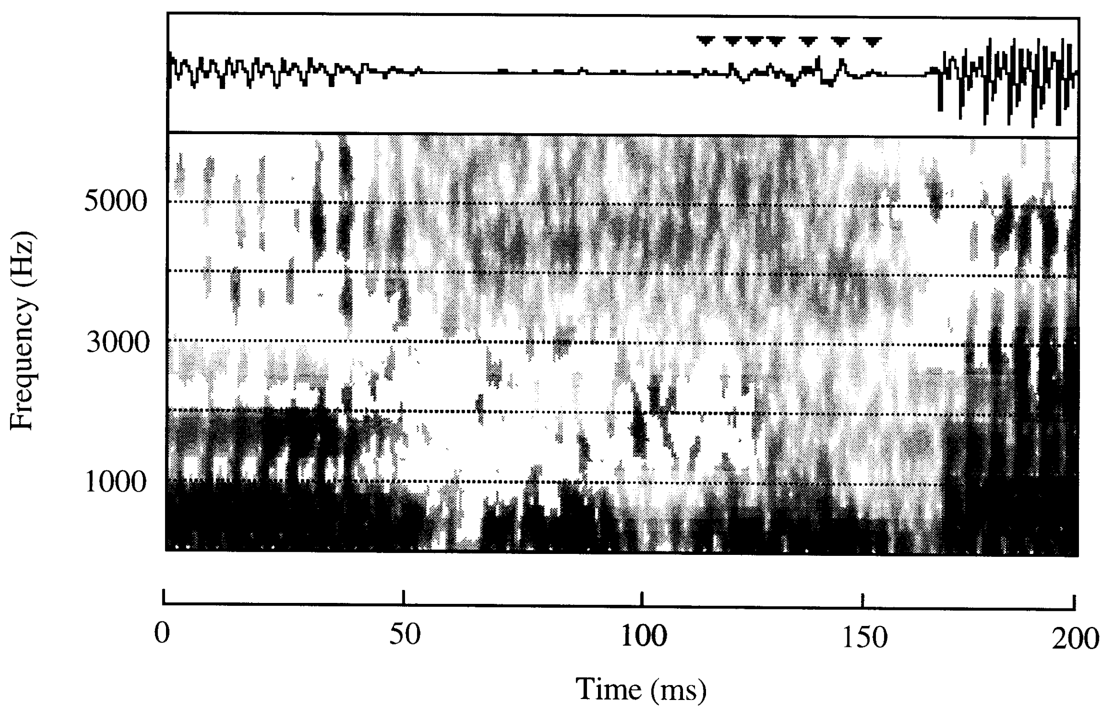
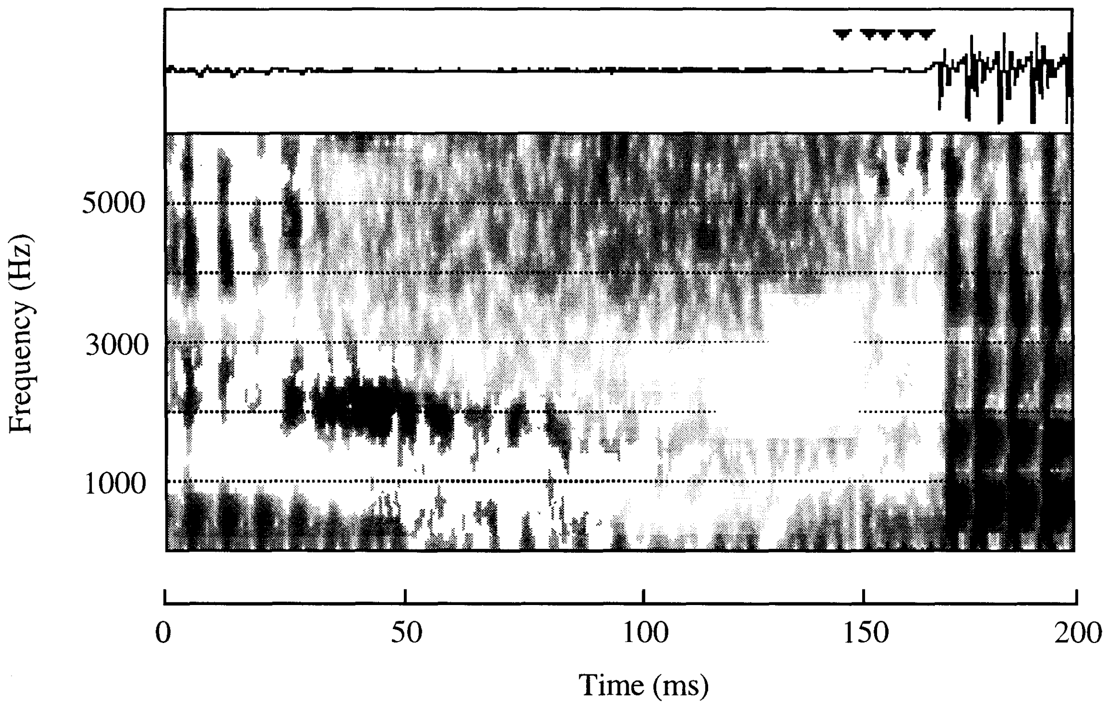


Figure 3.7. Example of prevoicing for class A [s] with five contiguous periods of voicing at the offset of frication designated in the waveform display by markers.



In addition, a number of the fricatives exhibited voicing at the offset of the consonant without being voiced throughout. Consonants with three or more periods of voicing adjoining the onset of the following vowel were classified as 'prevoiced'. A class A [s] exhibiting prevoicing is presented in Figure 3.7.

3.3. Results

Both the class A and the class B stops and affricates are voiceless for the majority of tokens. Both the class A and the class B fricatives are voiceless or partially voiced for the majority of tokens. However, the class B obstruents show a greater percentage of partially voiced and voiced tokens than class A. In contrast to the obstruents, the class A [h] and class B [ɦ] are voiced or partially voiced for the majority of tokens. Comparable numbers of tokens of the class A [h] are voiced and partially voiced; however, the majority of class B [ɦ] tokens are voiced. These findings appear in Figure 3.8. These results are discussed in more detail in the remainder of this section.

3.3.1. Stops and affricates

The class A stops and affricates are voiceless for the majority of the tokens, 542 tokens representing 94% of the class A stops and affricates. There are 33 tokens exhibiting partial voicing. However, all of these tokens are from speaker EF, indicating that partial voicing is not characteristic of the class A stops and affricates, in general. None of the class A stops and affricates are voiced. The majority of the tokens of class B stops and affricates are also voiceless, 408 tokens representing 66% of the stops and affricates. A greater number of the class B tokens are partially voiced, 183 representing 30% of the stops and affricates. In addition, 24 tokens are voiced; these tokens, however, originate from speaker EF, indicating that full voicing is not characteristic of the class B stops and affricates. These findings are summarized in Table 3.1.

Figure 3.8. The percentage of tokens of class A and class B consonants classified as voiceless, partially voiced, and voiced.

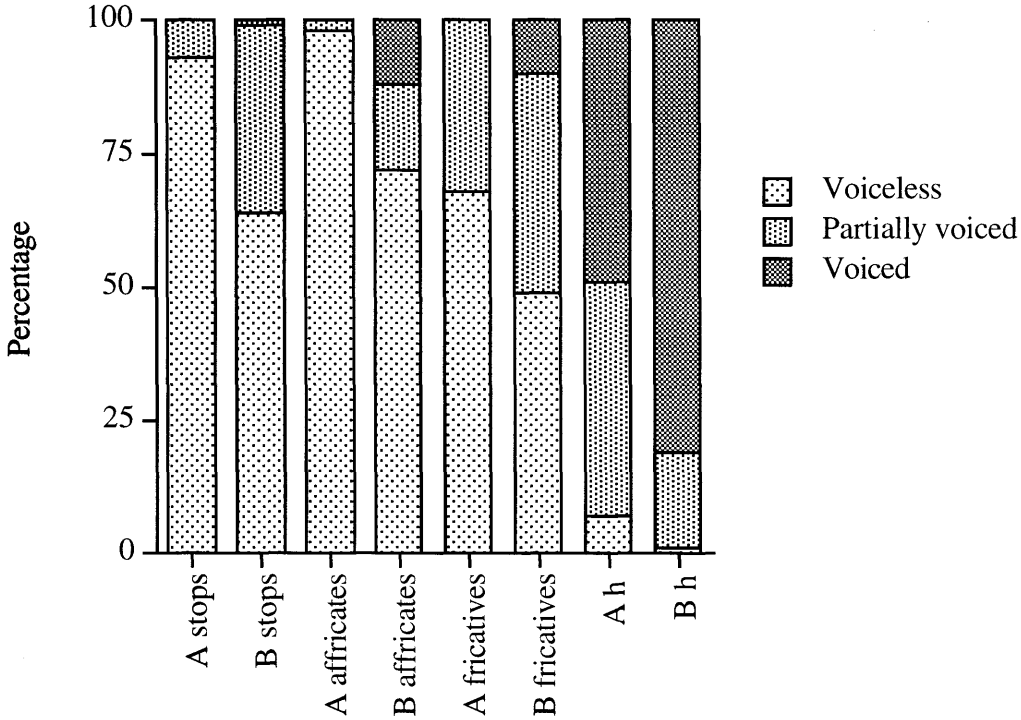


Table 3.1. The number of tokens of class A and class B stops and affricates classified as voiceless, partially voiced, and voiced and the percentage according to place of articulation and consonant class.

	Voiceless		Partially voiced		Voiced	
p	129	(90%)	15	(10%)	0	(0%)
b	52	(34%)	100	(65%)	1	(1%)
t	136	(95%)	7	(5%)	0	(0%)
d	115	(76%)	36	(24%)	0	(0%)
tʃ	141	(98%)	3	(2%)	0	(0%)
dʒ	118	(72%)	26	(16%)	19	(12%)
k	136	(94%)	8	(6%)	0	(0%)
g	123	(83%)	21	(21%)	4	(3%)
$\bar{x}_A$	542	(94%)	33	(6%)	0	(0%)
$\bar{x}_B$	408	(66%)	183	(30%)	24	(4%)

3.3.2. Fricatives

In a similar manner to the class A stops and affricates, the class A fricatives are voiceless for the majority of the tokens, 290 tokens representing 68% of the class A fricatives. 138 tokens are partially voiced, representing 32% of the class A fricatives. None of the class A fricatives are voiced. 49% of the class B fricatives are voiceless and 41% are partially voiced. Finally, 45 tokens are voiced; however, all of these tokens are from speaker EF, indicating that full voicing is not characteristic of the class B fricatives. These findings are summarized in Table 3.2.

Table 3.2. The number of tokens of class A and class B fricatives classified as voiceless, partially voiced, and voiced and the percentage according to place of articulation and consonant class.

	Voiceless		Partially voiced		Voiced	
f	95	(67%)	47	(33%)	0	(0%)
v	70	(46%)	68	(44%)	15	(10%)
s	87	(60%)	59	(40%)	0	(0%)
z	48	(33%)	81	(56%)	16	(11%)
ɬ	108	(77%)	32	(23%)	0	(0%)
ɮ	104	(67%)	37	(24%)	14	(9%)
$\bar{x}_A$	290	(68%)	138	(32%)	0	(0%)
$\bar{x}_B$	222	(49%)	186	(41%)	45	(10%)

The class A fricatives have a greater percentage of tokens with intermittent voicing, 160 tokens representing 37% of the class A fricatives. 25% of the class B fricatives exhibit intermittent voicing as seen in Table 3.3. The sibilants exhibit a greater number of tokens with intermittent voicing than the non-sibilant fricatives. Moreover, there is a larger percentage of partially voiced tokens which exhibit intermittent voicing than voiceless tokens which exhibit intermittent voicing. Thus, in the case that voicing persists for several periods into the fricative there is a greater probability of intermittent voicing occuring during the fricative than if voicing had ceased more abruptly at the onset of the fricative.

Table 3.3. The number of tokens of class A and class B fricatives exhibiting intermittent voicing and the percentage according to degree of voicing, place of articulation, and consonant class.

	Voiceless		Partially voiced		Total	
f	27	(19%)	14	(10%)	41	(29%)
v	11	(7%)	8	(5%)	19	(9%)
s	38	(26%)	34	(23%)	72	(49%)
z	18	(12%)	39	(27%)	57	(39%)
ɬ	29	(21%)	18	(13%)	47	(34%)
ɮ	16	(10%)	10	(6%)	26	(17%)
$\bar{x}_A$	94	(22%)	66	(15%)	160	(37%)
$\bar{x}_B$	45	(10%)	57	(13%)	102	(23%)

The class A fricatives have a greater percentage of tokens with prevoicing, 152 tokens representing 36% of the class A fricatives. 20% of the class B fricatives exhibit prevoicing as seen in Table 3.4.

Table 3.4. The number of tokens of class A and class B fricatives exhibiting prevoicing and the percentage according to degree of voicing, place of articulation, and consonant class.

	Voiceless		Partially voiced		Total	
f	30	(21%)	16	(34%)	46	(32%)
v	5	(3%)	10	(7%)	15	(10%)
s	35	(24%)	41	(28%)	76	(52%)
z	13	(9%)	40	(28%)	53	(37%)
ɬ	21	(15%)	9	(6%)	30	(21%)
ɮ	14	(9%)	8	(5%)	22	(14%)
$\bar{x}_A$	86	(20%)	66	(15%)	152	(36%)
$\bar{x}_B$	32	(7%)	58	(13%)	90	(20%)

3.3.3. Class A [h] and class B [ɦ]

In contrast to the class A and class B obstruents, class A [h] and class B [ɦ] are partially or fully voiced in the majority of tokens. [h] is voiced in 70 tokens representing 49% of the class A [h]'s. 64 tokens are partially voiced, and 10 tokens are voiceless. The majority of the tokens of class B [ɦ] are voiced, 113 tokens representing 81% of the [ɦ]'s. 22 tokens are partially voiced representing 18% of the class B [ɦ]'s; 2 tokens are voiceless. 11 of the 12 tokens of [h] and [ɦ] which are voiceless originate from speaker EF, suggesting that voicelessness is not characteristic in general of these consonants. These findings are summarized below in Table 3.5.

Table 3.5. The number of tokens of class A [h] and class B [ɦ] classified as voiceless, partially voiced, and voiced and the percentage according to consonant class.

	Voiceless		Partially voiced		Voiced	
h	10	(7%)	64	(44%)	70	(49%)
ɦ	2	(1%)	22	(18%)	113	(81%)

For the class A [h] and class B [ɦ], the majority of the partially voiced and voiceless tokens exhibit intermittent voicing. As with the class A and class B obstruents, the class A [h] exhibits a greater percentage of tokens with intermittent voicing than the class B [ɦ], as seen in Table 3.6.

Table 3.6. The number of tokens of class A [h] and class B [ɦ] exhibiting intermittent voicing and the percentage according to degree of voicing and consonant class.

	Voiceless		Partially voiced		Total	
h	7	(5%)	48	(33%)	55	(38%)
ɦ	2	(1%)	20	(15%)	22	(16%)

3.4. Discussion

According to this qualitative investigation, the majority of tokens of both class A and class B obstruents are voiceless. The two classes differ, however, in the frequency of occurrence and perseverance of voicing at the onset of the obstruent. Furthermore, a proportion of the class A and class B fricatives exhibit intermittent voicing. The class A fricatives exhibit a greater number of tokens with intermittent voicing than the class B fricatives; a chi-square analysis indicates that consonant class has a significant effect on the occurrence of intermittent voicing ($\chi^2=14.89$, $p<.0001$). The class A fricatives also exhibit a greater number of tokens with prevoicing; a chi-square analysis indicates a significant effect of consonant class on the occurrence of prevoicing ($\chi^2=18.39$, $p<.0001$). In contrast to the obstruents, the majority of the tokens of class A [h] and class B [ɦ] are completely voiced. Most of the remaining tokens of [h] and [ɦ] exhibit intermittent voicing. These results confirm the impressionistic description of both the class A and class B obstruents as primarily voiceless. In the next chapter these and other temporal properties of the class A and class B consonants and adjacent vowels will be investigated in detail.

Chapter 4: The temporal properties of the class A and class B consonants

4.1. Introduction

As established in the preceding chapter, the class A and class B obstruents are primarily voiceless in the majority of tokens. The class A [h] and class B [ɦ], on the other hand, are voiced or partially voiced in the majority of tokens. This chapter investigates the temporal properties of these consonants. It is shown that the two classes exhibit small but significant differences in their temporal properties.

4.2. Procedure

Duration measurements were made from a waveform display on CSL with reference to a simultaneously displayed, time-aligned narrowband spectrogram (bandwidth of 586 Hz) and energy display.

Five duration measurements were made for the stops and affricates. The first measurement was the duration of the vowel [i] in the carrier phrase preceding the consonants under investigation from the onset to offset of formant structure. The second measurement was the duration of the offset voicing time (OFT) of the closure from the point in which the formants of the preceding vowel dissipate to the point in the closure at which voicing ceases. The third measurement was the duration of the voiceless closure from the cessation of voicing to the release. The fourth measurement was the duration of voice onset time (VOT) from the burst indicating release of the stop closure to the onset of periodicity in the vowel. In the case of the affricates, the fourth measurement corresponds to the duration of the release of the affricate. The fifth measurement was the duration of the vowel [a] of the target syllable from the onset to offset of formant structure. These measurements are shown in Figure 4.1. for the class A stop [t]. The duration of the vowel [i] is demarcated by the first two markers in the waveform display. The second and third markers indicate the period of offset voicing for the class A [t]. The third and fourth markers set off the period of voiceless closure for the stop. The VOT of [t] is demarcated by the fourth and fifth markers in the waveform display. Finally, the last two markers delimit the vowel [a].

In the case of the fricatives, four durations were measured. The first was the duration of the vowel [i] preceding the fricative from the onset to offset of formant structure. The second measurement was the duration of the OFT from the onset of the fricative as indicated by the onset of frication and the dissipation of the format structure of the preceding vowel to the point in the fricative at which voicing ceases. The third measurement was the remaining duration of the fricative from the cessation of voicing to the onset of the following vowel. As discussed above, the fricatives exhibit intermittent voicing as well as prevoicing. Thus, the section of the fricative from the cessation of perseverative voicing to the onset of the following vowel includes periods of voiceless frication and voiced frication; nonetheless, this duration of the fricative is referred to as 'voiceless frication' for the purpose of the discussion below. Finally, the fourth measurement was the duration of the vowel [a]. These measurements are shown in Figure 4.2. The first two markers in the waveform display delimit the vowel [i] and the last two markers the vowel [a]; the second and third markers indicate the offset voicing in the class A fricative [s]. The remainder of [s] is set off by the third and fourth markers.

Figure 4.1. Example of segmentation of the vowel [i] and the class A stop [t] and the following vowel [a] from time-aligned waveform and spectrogram displays.

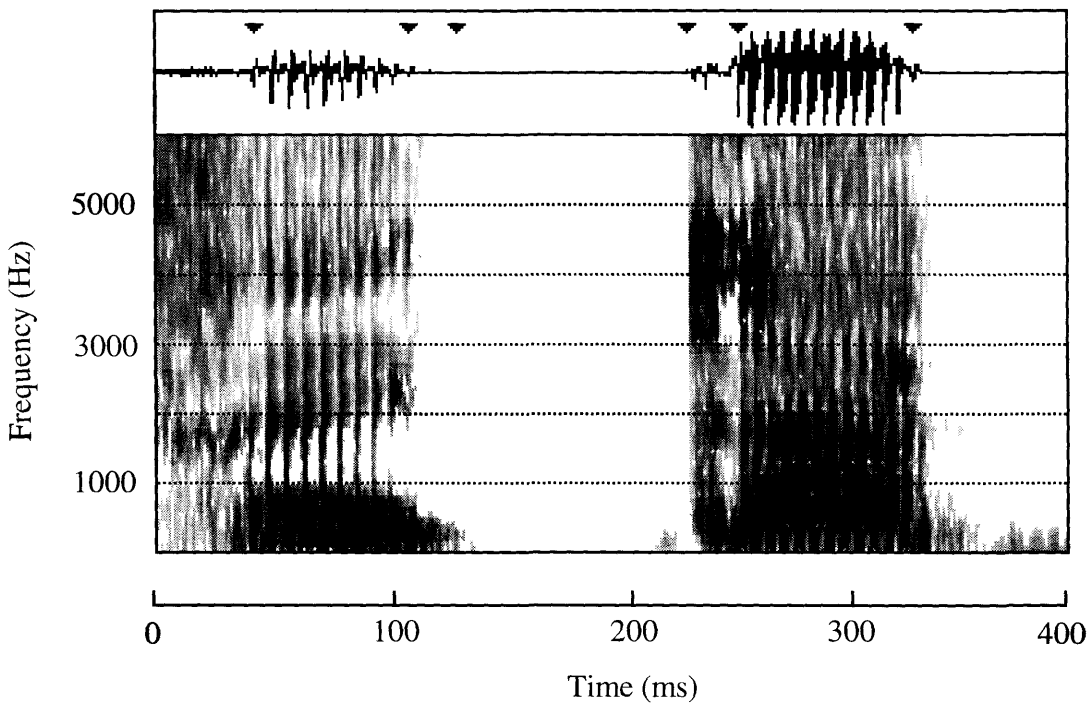
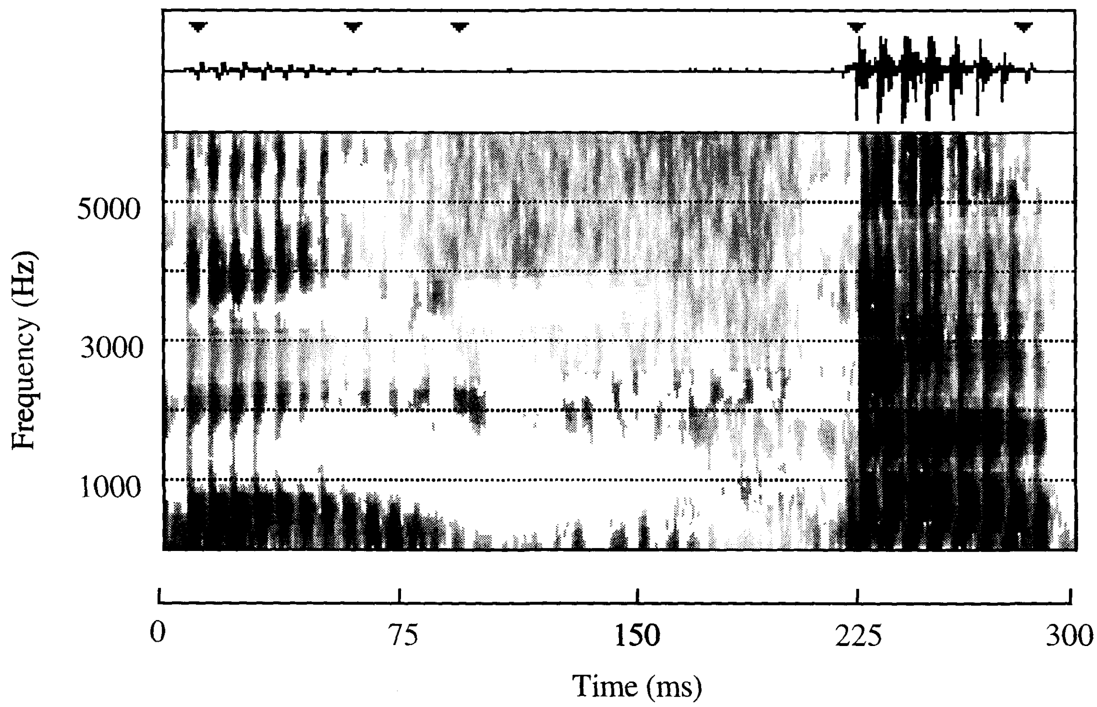
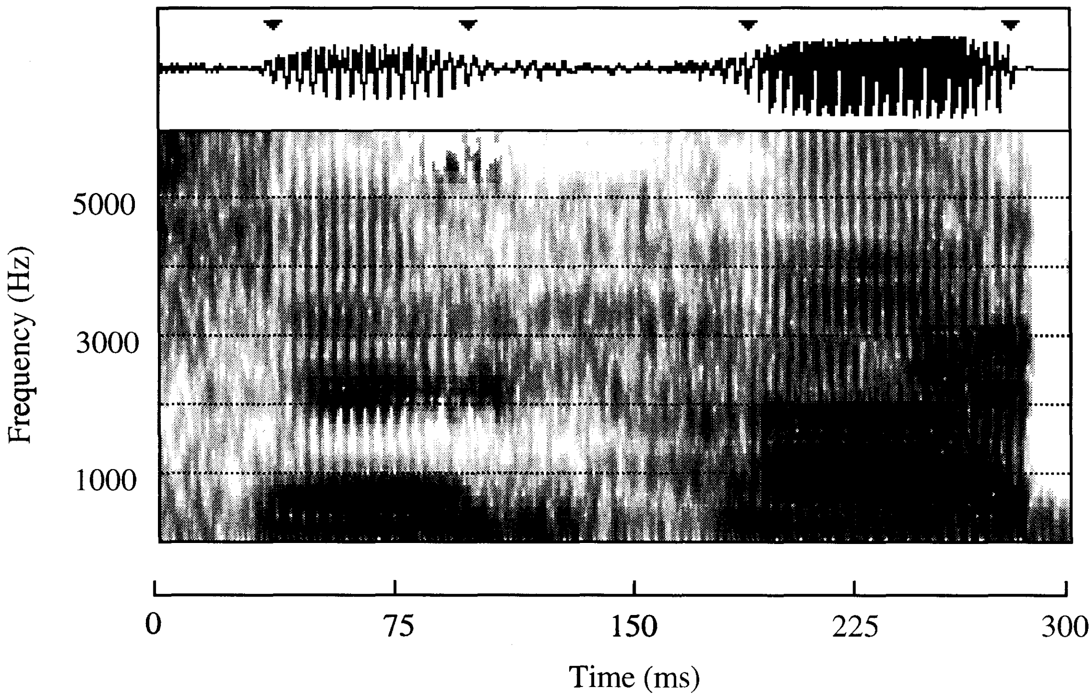


Figure 4.2. Example of segmentation of [i], the class A fricative [s], and the vowel [a] from time-aligned waveform and spectrogram displays.



Three duration measurements were made for the class A [h] and class B [ɦ] corresponding to the duration of the preceding vowel [i], the class A [h] and class B [ɦ], and the following vowel [a]. As noted earlier, the onset and offset of [h] and [ɦ] were difficult to determine. The reduction of definition in formant structure, lower amplitude, and presence of frication were used as criteria to segment [h] and [ɦ] from adjoining vowels. Due to the inherent indeterminacy in segmenting these consonants, however, the duration measurements should be considered only approximate. In Figure 4.3. the first two markers in the waveform display delimit the vowel [i] and the last two markers the vowel [a]; the second and third markers indicate the duration of the class A [h].

Figure 4.3. Example of segmentation of the vowel [i], the class A [h], and the vowel [a] from time-aligned waveform and spectrogram displays.



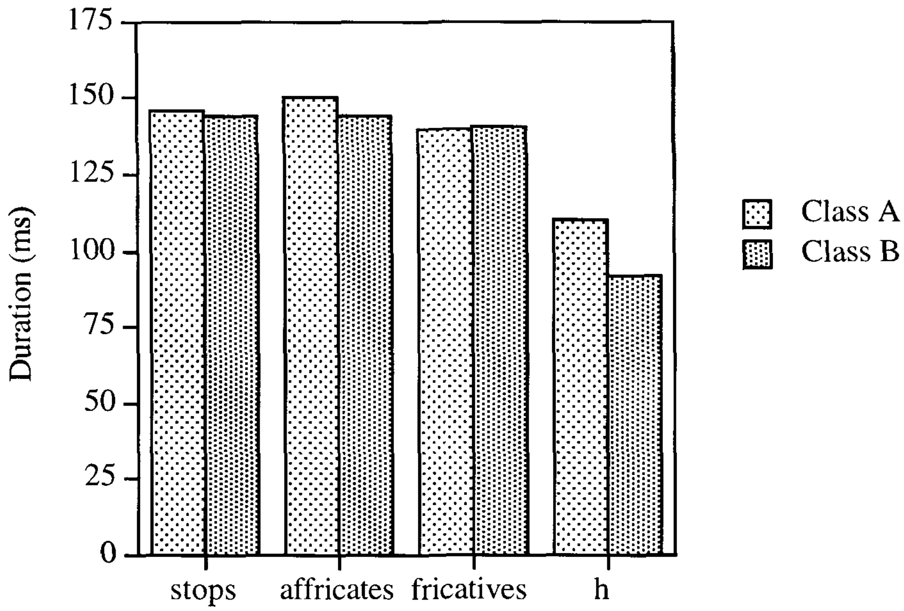
A three-factor ANOVA was performed on each durational component of the class A and class B consonants and adjoining vowels in order to test for the effects of consonant class, place of articulation, and speaker identity. If the interaction of class and place was significant, separate two-factor ANOVA's were performed for each place of articulation with the factors consonant class and speaker identity to determine whether the effect of consonant class was significant in each place of articulation. Post-hoc comparisons of means were then conducted for each pairwise comparison of place of articulation with the Spjotvoll and Stoline test (SST) to determine whether the means for the separate places of articulation were distinct.

In order to determine the effect of tone on duration, a three-factor analysis of variance was performed on each durational component of the class A and class B consonants and adjoining vowels to test for the effects of consonant class, tone (high versus mid), and speaker identity. Tone does not have a significant main effect.

4.3. Results

The class A and class B consonants have comparable durations as illustrated in Figure 4.4. There is a tendency for the class A consonants to have longer durations as seen with the class A [h] as well as the class A stops and affricates. Although the difference is small, it is statistically reliable in the case of the class A [h] and affricates.

Figure 4.4. The mean duration (ms) of the class A and class B consonants.



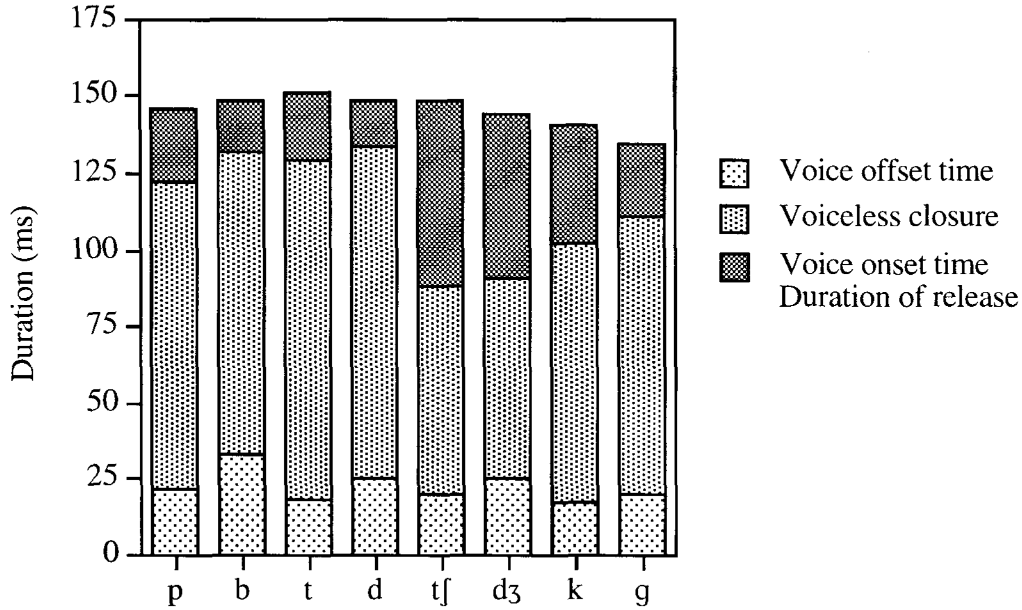
These results are discussed in the remainder of this section. The durations of the intervals comprising the consonants are also presented. In addition, the durations of the preceding and following vowels are discussed.

4.3.1. Stops and affricates

4.3.1.1. Consonant duration

The class A and class B stops and affricates exhibit subtle differences in total duration as well as the duration of OFT, voiceless closure, and VOT as seen in Figure 4.5. The class A and class B labial and alveolar stops do not differ in total duration, the sum of the duration of OFT, voiceless closure, and VOT. The velar stops and the affricates differ, though, with class A having a longer duration. The class A stops and affricates have significantly shorter OFT. The two classes do not differ in the duration of the voiceless closure, though. The class A stops have a longer VOT; the class A affricates have a longer release.

Figure 4.5. The mean duration (ms) of the class A and class B consonants.



4.3.1.1.1. Duration of consonant

The overall mean duration of the class A stops and affricates is 3 ms longer than that of the class B stops and affricates ($F[1,983]=17.52$, $p<.0001$). However, the durations of the class A and class B labial and alveolar stops are not significantly different as summarized in Table 4.1. The affricates and velar stops show a more robust difference.

Table 4.1. Mean consonant duration (ms) for class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	146	17	142	2.43	.1199
b	148	17	148		
t	152	17	110	3.18	.0759
d	149	15	107		
tʃ	150	18	104	13.09	.0004
dʒ	144	13	107		
k	141	18	139	19.75	.0001
g	135	19	141		
$\bar{x}_A$	147	18	495	17.52	.0001
$\bar{x}_B$	144	17	503		

The main effect of place of articulation is significant (F[3,938]=35.28, p<.0001). The overall durations of the stops at different places and affricates are significantly distinct with the exception of the labial stops and the affricates as indicated by post-hoc comparisons between means with the SST. The alveolar stops have the longest duration, the labial stops are intermediate, and the velars are the shortest.

4.3.1.1.2. Duration of closure

The class B stops have a 7 ms longer mean closure duration than the class A stops. The difference is small but statistically reliable (F[1,938]=53.25, p<.0001). In the case of the affricates, though, the difference in closure duration is not significant. The mean closure durations for the class A and class B stops and affricates appear in Table 4.2.

Table 4.2. Mean closure duration (ms) for class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	122	15	142	51.13	.0001
b	131	17	148		
t	130	16	110	7.94	.0053
d	134	14	107		
tʃ	88	16	104	1.73	.1905
dʒ	91	15	107		
k	102	17	139	33.11	.0001
g	111	18	141		
$\bar{x}_A$	111	22	495	53.25	.0001
$\bar{x}_B$	118	23	503		

The main effect of place of articulation is significant (F[3,938]=482.74, p<.0001). The closure durations of the labial, alveolar, and velar stops and the affricates are significantly distinct from each other as indicated by post-hoc comparisons between means with the SST. The closure duration is longest for the alveolars, shortest for the velars, and intermediate for the labials. Finally, the affricates have a substantially shorter closure duration than the stops.

4.3.1.1.3. Duration of offset voicing time (OFT)

The class B stops and affricates have a 7 ms longer OFT duration than the class A stops and affricates (F[1,938]=218.68, p<.0001). The mean OFT durations for the class A and class B stops and affricates appear in Table 4.3. The main effect of place of articulation is significant (F[3,938]=77.92, p<.0001). The OFT durations of the labial, alveolar, and velar stops are significantly distinct as indicated by post-hoc comparisons between means with the SST. The OFT duration of the affricates is not significantly different from the alveolar stops. The OFT duration is longest for the labials, shortest for the velars, and the alveolars and affricates are intermediate. Similar findings of a place effect on OFT of voiceless stops have been reported in the literature (Suomi 1980; Keating 1984).

Table 4.3. Mean OFT duration (ms) for class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	22	9	142	117.44	.0001
b	33	17	148		
t	18	6	110	36.87	.0001
d	25	11	107		
tʃ	20	6	104	34.91	.0001
dʒ	25	8	107		
k	17	9	139	23.35	.0001
g	20	15	141		
$\bar{x}_A$	19	8	495	218.68	.0001
$\bar{x}_B$	26	14	503		

4.3.1.1.4. Duration of voiceless closure

The class A and class B stops and affricates do not differ in the duration of the voiceless closure ($F[1,938]=1.31$, $p<.2525$). In the case of the velars, though, the class B stops have a 6 ms longer mean voiceless closure duration as shown in Table 4.4.

Table 4.4. Mean voiceless closure duration (ms) for class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	100	18	142	.43	.5214
b	99	27	148		
t	111	16	110	.63	.4292
d	109	18	107		
tʃ	68	17	104	.93	.3361
dʒ	66	17	107		
k	85	17	139	7.69	.0059
g	91	25	141		
$\bar{x}_A$	92	23	495	1.31	.2525
$\bar{x}_B$	92	27	503		

The main effect of place of articulation is significant ($F[3,398]=349.46$, $p<.0001$). The voiceless closure durations of the labial, alveolar, and velar stops as well as the affricates are significantly distinct as indicated by post-hoc comparisons between means with the SST. The alveolar stops have the longest voiceless closure duration followed by the labials, velars, and affricates.

4.3.1.1.5. VOT

The VOT's for Musey stops are uniformly short. However, an analysis of variance indicates a significant effect of consonant class on VOT ($F[1,741]=650.53$, $p<.0001$). The class A stops have a 10 ms longer mean VOT than the class B stops as seen in Table 4.5.

Table 4.5. Mean VOT (ms) for class A and class B stops according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	24	8	142	120.85	.0001
b	17	7	148		
t	22	6	110	153.66	.0001
d	15	4	107		
k	39	7	139	603.97	.0001
g	24	5	141		
$\bar{x}_A$	29	10	391	650.53	.0001
$\bar{x}_B$	19	7	396		

The main effect of place of articulation is significant ($F[2,741]=481.87$, $p<.0001$). The VOT of the stops is significantly distinct as indicated by post-hoc comparisons between means with the STT. The VOT is longest for the velars. The alveolars exhibit the shortest VOT with the labials slightly longer. It has been reported that VOT durations increase from labial to alveolar to velar (Fischer-Jørgensen 1964; Crystal and House 1988). The labials in Musey have longer VOT than the alveolars in contrast to this pattern.

4.3.1.1.6. Duration of affricate release

The class A affricate have a 8 ms longer release than the class B affricate ($F[1,296]=59.51$, $p<.0001$) as illustrated in Table 4.6.

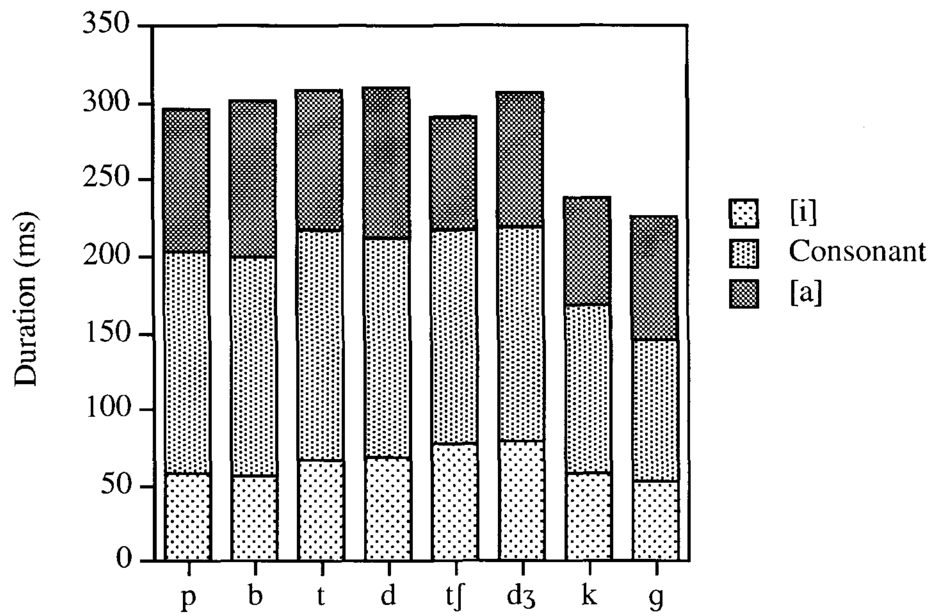
Table 4.6. Mean release duration (ms) for class A and class B affricates.

	Mean	Std. Dev.	n	F-value	P-value
tʃ	61	11	152	59.51	.0001
dʒ	53	10	160		

4.3.1.2. Duration of adjacent vowels

The class A and class B stops and affricates were produced in an intervocalic context between the vowels [i] and [a]. The duration of the preceding vowel [i] does not differ significantly with the class of the following consonant. The duration of the vowel [a], however, is greater when preceded by the class B stops and affricates. These durations are summarized in Figure 4.6.

Figure 4.6. Mean duration (ms) of class A and class B stops and affricates and the adjacent vowels [i] and [a].



4.3.1.2.1. Duration of [a]

The mean duration of the vowel of the target syllable is 11 ms longer when preceded by the class B stops and affricates than when preceded by the class A stops and affricates (F[1,1037]=433.28, p<.0001). The mean durations for [a] appear in Table 4.7.

Table 4.7. Mean duration of [a] (ms) preceded by class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	93	19	142	73.65	.0001
b	102	17	148		
t	91	29	110	48.50	.0001
d	98	24	107		
tʃ	73	19	152	220.52	.0001
dʒ	87	20	160		
k	70	17	139	140.87	.0001
g	82	18	141		
$\bar{x}_A$	81	23	543	433.28	.0001
$\bar{x}_B$	92	21	556		

The results also appear to indicate that place of articulation of the preceding consonant has a significant main effect on the duration of [a] (F[3,1037]=444.61, p<.0001). This apparent effect of place is likely to be largely an artifact, though, resulting from the differences in the coda consonant of the target syllables. As described above, the /CVC/ tokens with labial stops in onset position have [s] in coda position, the tokens with alveolar stops in onset position have the coda [t], and the tokens with velar stops and affricates in onset position have [k] in coda position.

4.3.1.2.2. Duration of [i]

The class A and class B stops and affricates are preceded in the carrier phrase by the vowel [i]. The duration of this vowel does not differ when preceding the class A stops and affricates as opposed to the class B stops and affricates (F[1,938]=.73, p<.3929). In the case of the velars, though, the mean duration of [i] is 5 ms longer when the following consonant is the class A [k]. Although this result is statistically significant, the cumulative pattern of the results suggest that this is an accidental finding. The mean durations are presented in Table 4.8.

Table 4.8. Mean duration of [i] (ms) preceding class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

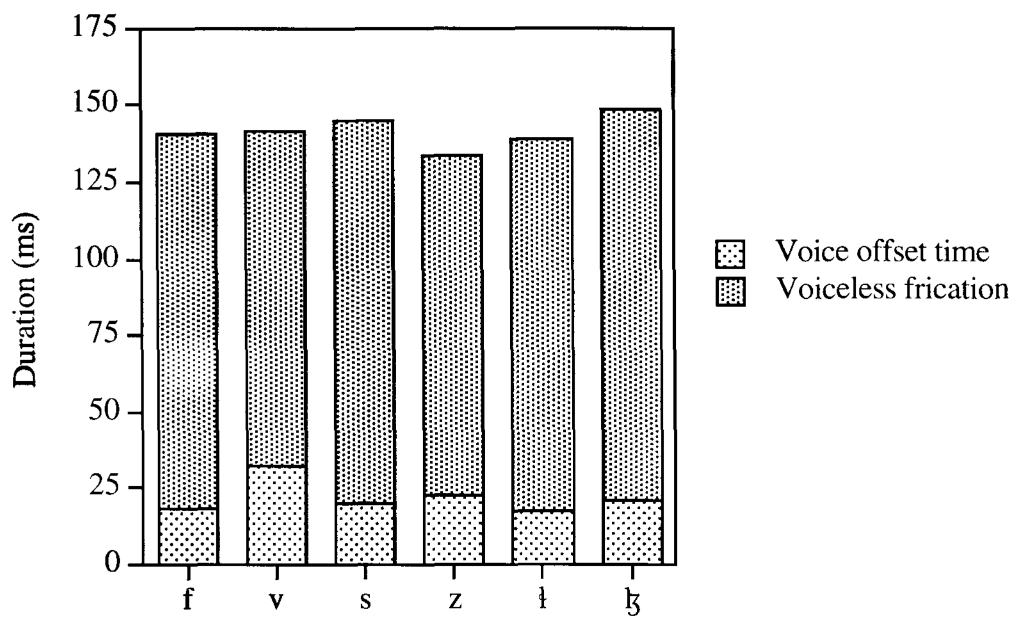
	Mean	Std. Dev.	n	F-value	P-value
p	58	27	142	.09	.7652
b	56	29	148		
t	67	29	110	.97	.3268
d	69	34	107		
tʃ	78	27	104	.24	.6240
dʒ	79	27	107		
k	58	30	139	8.37	.0041
g	53	29	141		
$\bar{x}_A$	64	29	495	.731	.3929
$\bar{x}_B$	63	31	503		

4.3.2. Fricatives

4.3.2.1. Duration of fricative

The class A and class B fricatives do not differ significantly in total duration. However, the two classes do differ in the duration of offset voicing and voiceless frication. In a similar manner to the class B stops and affricates, the class B fricatives have a longer OFT. The class A fricatives, in contrast, have a longer duration of voiceless frication. The magnitudes of these respective differences in duration are comparable; thus, the total duration of the class A and class B fricatives are similar. These durations are summarized in Figure 4.7.

Figure 4.7. The mean duration (ms) of the class A and class B fricatives.



The durations of the fricatives as well as the durations of the preceding and following vowels are discussed in the remainder of this section.

4.3.2.1.1. Duration of fricative

The class A and class B fricatives do not differ in duration ($F[1,741]=2.02$, $p<.1557$). In the case of the sibilants, though, the class A [s] is 10 ms longer than the class B [z] ($F[1,741]=22.05$, $p<.0001$) as seen in Table 4.9.

Table 4.9. Mean consonant duration (ms) for class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	141	18	141	.06	.8124
v	142	25	149		
s	145	19	122	22.05	.0001
z	135	22	115		
ɬ	137	24	136	4.07	.0448
ɮ	142	29	124		
$\bar{x}_A$	141	21	399	2.02	.1557
$\bar{x}_B$	140	26	388		

The main effect of place of articulation is not significant (F[2,741]=2.95, p<.0530). The fricative durations of the labial fricatives, sibilants, and lateral fricatives are not significantly distinct according to post-hoc comparisons between means with the SST. Several studies have reported, however, that sibilants have longer duration than non-sibilants in other languages (Behrens and Blumstein 1988, You 1979).

4.3.2.1.2. Duration of offset voicing time (OFT)

The OFT duration of the class B fricatives is 8 ms longer than that of the class A fricatives (F[1,743]=121.20, p<.0001). The mean OFT durations for the class A and class B fricatives appear in Table 4.10.

Table 4.10. Mean OFT duration (ms) for class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	18	8	141	257.04	.0001
v	32	32	149		
s	20	16	122	10.69	.0012
z	23	12	115		
ɬ	17	9	136	24.01	.0001
ɮ	21	23	126		
$\bar{x}_A$	18	11	399	121.20	.0001
$\bar{x}_B$	26	25	390		

The main effect of place of articulation is significant (F[2,743]=7.34, p<.0007). The OFT durations of the labial fricatives, sibilants, and lateral fricatives are significantly distinct as indicated by post-hoc comparisons between means with the SST. The OFT duration is longest for the labials, the sibilants are intermediate, and the laterals the shortest.

4.3.2.1.3. Duration of voiceless frication

The mean interval of voiceless frication of the class A fricatives is 7 ms longer than that of the class B fricatives (F[1,794]=33.61, p<.0001). The class A and class B lateral fricatives do not differ in duration, though. The mean voiceless frication durations for the class A and class B fricatives are shown in Table 4.11. The main effect of place of articulation is significant (F[2,794]=16.42, p<.0001). The mean voiceless frication duration of the lateral fricatives is significantly longer than that of the labial fricatives and the sibilants, but only because the voiced lateral fricatives are longer. The class A voiceless fricatives at different places are not statistically distinct in duration.

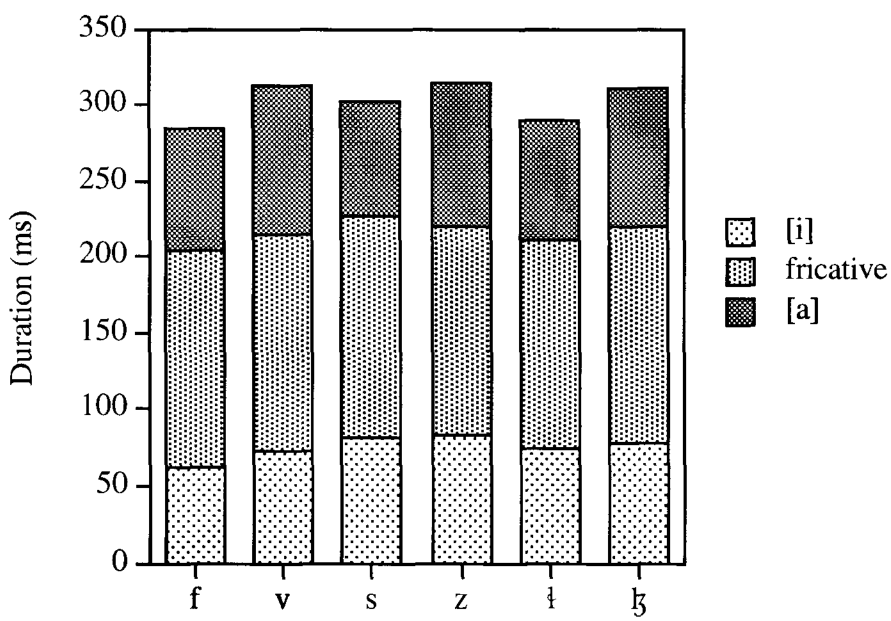
Table 4.11. Mean voiceless frication duration (ms) for class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	123	19	146	64.09	.0001
v	110	22	153		
s	125	18	124	45.25	.0001
z	111	21	138		
ɬ	122	25	141	2.62	.1071
ɮ	128	34	138		
$\bar{x}_A$	123	21	411	33.61	.0001
$\bar{x}_B$	116	27	429		

4.3.2.2. Duration of adjacent vowels

There are small but reliable differences in the durations of the adjacent vowels depending on the consonant class of the fricatives. The vowel [i] is longer when preceding the class B fricatives. The vowel [a] is also longer when the preceding fricative is from class B. These durations are summarized in Figure 4.8.

Figure 4.8. Mean duration (ms) of the class A and class B fricatives and the adjacent vowels [i] and [a].



4.3.2.2.1. Duration of [a]

The mean duration of the vowel of the target syllable is 17 ms longer when preceded by the class B fricatives than when preceded by the class A fricatives ($F[1,751]=222.38$, $p<.0001$). The mean durations for [a] appear in Table 4.12.

Table 4.12. Mean duration of [a] (ms) preceded by class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	81	20	130	19.44	.0001
v	98	22	141		
s	76	16	150	282.55	.0001
z	95	19	146		
ɬ	78	15	119	136.33	.0001
ɮ	90	15	111		
$\bar{x}_A$	78	17	399	222.38	.0001
$\bar{x}_B$	95	19	398		

The main effect of place of articulation is significant ($F[2,751]=40.80$, $p<.0001$). The duration of [a] when preceded by the labial fricatives, sibilants, and lateral fricatives is significantly distinct as indicated by post-hoc comparisons between means with the SST. In this case there is no confound with the final C of the target syllable; all syllables are of the form /Cat/.

4.3.2.2.2. Duration of [i]

The mean duration of [i] is 5 ms longer when preceding the class B fricatives as opposed to the class A fricatives ($F[1,602]=12.01$, $p<.0006$) as seen in Table 4.13. In the case of the sibilants, though, consonant class does not have a significant effect on the duration of [i]. Data from speakers EF and TA were excluded because [i] was reduced before sibilants for these speakers.

Table 4.13. Mean duration of [i] (ms) followed by class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

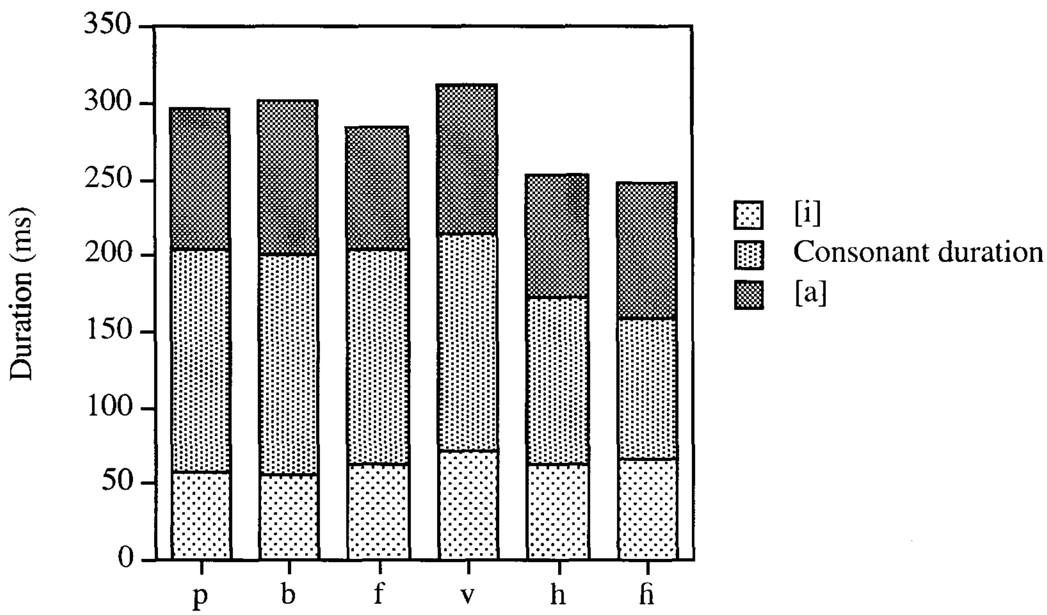
	Mean	Std. Dev.	n	F-value	P-value
f	63	25	106	10.18	.0016
v	72	32	113		
s	81	25	100	.82	.3670
z	84	27	108		
ɬ	74	23	103	4.32	.0390
ɮ	78	31	108		
$\bar{x}_A$	73	26	309	12.01	.0006
$\bar{x}_B$	78	30	329		

Place of articulation has a significant main effect on the duration of [i] (F[2,602]=26.78, p<.0001). [i] has the longest duration when followed by the labial fricatives, an intermediate duration when followed by the sibilants, and the shortest duration when followed by the lateral fricatives.

4.3.3. Class A [h] and class B [ɦ]

In a similar manner to the class A and class B obstruents, the class A [h] and class B [ɦ] exhibit a small difference in duration. There are also small differences in the duration of the adjacent vowels according to the consonant class of the h. These temporal characteristics of the class A [h] and class B [ɦ] are presented in Figure 4.9. with data for the class A and class B labial stops and fricatives for comparison.

Figure 4.9. Mean durations (ms) of class A and class B consonants and adjacent vowels [i] and [a].



4.3.3.1. Duration of class A [h] and class B [ɦ]

The class A [h] is 18 ms longer in duration than the class B [ɦ] (F[1,265]=77.67, p<.0001) as seen in Table 4.14.

Table 4.14. Mean duration (ms) for class A [h] and class B [ɦ].

	Mean	Std. Dev.	n	F-value	P-value
h	110	25	142	77.67	.0001
ɦ	92	20	139		

4.3.3.2. Duration of adjacent vowels

4.3.3.2.1. Duration of [a]

The mean duration of the vowel of the target syllable is 10 ms longer when preceded by class B [ɦ] than when preceded by class A [h] (F[1,257]=186.73, p<.0001). The mean durations for [a] appear in Table 4.15.

Table 4.15. Mean duration of [a] (ms) preceded by class A [h] and class B [ɦ].

	Mean	Std. Dev.	n	F-value	P-value
h	79	14	147	186.73	.0001
ɦ	89	18	126		

4.3.3.2.2. Duration of [i]

The mean duration of [i] is 4 ms longer when preceding the class B [ɦ] as opposed to the class A [h] (F[1,254]=7.39, p<.0070) as seen in Table 4.16.

Table 4.16. Mean duration of [i] (ms) followed by class A [h] and class B [ɦ].

	Mean	Std. Dev.	n	F-value	P-value
h	63	20	136	7.39	.0070
ɦ	67	19	134		

4.4. Summary

The class A and class B consonants exhibit subtle temporal differences. The adjacent vowels also differ significantly in duration depending on the class of the adjoining consonant. In this final section several interpretations of the temporal properties of the adjacent vowels are considered. Then the temporal properties of the class A and class B consonants are summarized.

4.4.1. The adjacent vowels

The duration of the vowel of the target syllable [a] is significantly longer when preceded by a class B consonant. In a similar manner, the duration of the preceding vowel [i] is significantly longer when followed by the class B fricatives and class B [ɦ]. Explanations for these properties of the adjacent vowels are considered in this section.

The vowel [a] is significantly longer when preceded by a class B consonant. In the case of stops there is an inverse relationship between the VOT of the class A and class B stops and the duration of the following vowel [a]. In other words, there appears to be a trading relationship between VOT and the duration of the vowel. As the VOT duration increases, the vowel duration decreases. The sum of VOT and the duration of [a] is not significantly different for class A and class B stops (F[1,741]=.819, p=.3657). The trading relationship is confirmed by submitting the durations of [a] to a multiple regression with the independent factors including the VOT duration and dummy variables coding the place of articulation of the onset and the different consonants in coda position. The correlation of duration of VOT and the following vowel yielded r=.516 and r^2=.266; the regression is significant (F[3,786]=94.79, p<.0001). The component of the regression equation relating the duration of [a] to the release duration is significant at p>.0001. These findings suggest that there is a constant duration for the syllable nucleus (VOT+vowel) in Musey. Consequently, variation in VOT is compensated by the duration of the vowel.

It is also the case for the affricates that the class A affricates have a longer release duration than the class B affricates. The duration of [a] is longer after the class B affricates than after the class A affricates. However, the sum of the duration of the release and the vowel is significantly different after the two classes of affricates (F[1,296]=19.88, p=.0001). The absence of a trading relationship is confirmed by submitting the duration of [a] to a simple regression with the independent factor being the duration of release. The correlation of duration of release and the following vowel yielded r=.055 and r^2=.003; the regression is not significant (F[1,311]=.954, p=.3294). As will be discussed in the next chapter, the frication of the class B affricates has a lower amplitude than the frication of the class A affricates. Thus, the difference in duration of /a/ may be an artifact of the difficulty in measuring the duration of the frication of the affricate release and segmenting the offset of the release and the onset of the following vowel /a/.

In the case of the fricatives, the duration of the adjacent vowels is longer for the class B fricatives than for the class A fricatives. The sum of the fricative duration and the duration of [a] is significantly different for class A and class B fricatives (F[1,647]=4.96, p=.0262), being longer for the class B fricatives. The duration of [a] was submitted to a simple regression with the independent factor being the duration of the fricatives. The correlation yielded r=.172 and r^2=.030; the regression is significant (F[1,689]=21.04, p<.0001). In a similar manner, the sum of the fricative duration and the duration of [i] is significantly different for the two classes of fricatives (F[1,693]=20.63, p=.0001) suggesting the absence of a trading relationship. The duration of [i] was submitted to a simple regression with the independent factor being the duration of the following fricatives. The correlation yielded r=.054 and r^2=.003; thus, the regression is not significant (F[1,736]=2.15, p<.1428). These findings suggest that the difference in duration of the adjacent vowels may be an artifact of the difficulty in measuring the duration of frication and segmenting the transitions between fricatives and adjacent vowels.

The total duration of the fricatives plus adjacent vowels is significantly different (F[1,613]=22.20, p=.0001) with the class B sequence exhibiting a greater mean duration of 17 ms. The greater cumulative durations of the class B fricatives are apparent in Figure 4.8. The greater cumulative duration associated with class B suggests that these fricatives have a greater consonant duration than the class A fricatives. The difference in duration is obscured, however, by the difficulty in measuring the onset and offset of frication.

Finally, the duration of [a] is significantly longer after the class B [ɦ]. The preceding vowel [i] is also longer when followed by the class B [ɦ]. The effect of the class B [ɦ] on the duration of the adjacent vowels should be considered less reliable given the inherent difficulty of segmenting [h] and [ɦ] in an intervocalic context.

4.4.2. Consonants

The class A and class B consonants exhibit a number of subtle temporal differences. These temporal differences offer insights into the differences in production between the two clases but are unlikely to serve themselves as major distinctive properties of the two classes. The class A and class B stops and affricates have a small difference in consonant duration with a tendency for the class A stops and affricates to have the longer duration except for the labial stops. The class B fricatives appear to have a longer duration than the class A. The obstruents also differ in OFT with the class B obstruents showing a consistently longer OFT. The class A [h] and class B [ɦ] differ in duration with the class A [h] exhibiting an 18 ms longer duration. The principal durational properties of these consonants are shown in Table 4.17.

Table 4.17. Comparison of the durational properties of the class A and class B consonants including consonant duration (C), offset voicing time (OFT), duration of voicless closure (VC), and voice onset time/release duration (VOT).

	C	OFT	VC	VOT
Stops	Longer with class A	7 ms longer with class B	No difference	10 ms longer with class A
Affricates	6 ms longer with class A	5 ms longer with class B	No difference	8 ms longer with class A
Fricatives	Longer with class B	8 ms longer with class B	7 ms longer with class A	NA
h	18 ms longer with class A	NA	NA	NA

Chapter 5: The spectral properties of the class A and class B consonants

5.1. Introduction

In the previous two chapters the presence of voicing and the temporal properties of the class A and class B consonants were investigated. These investigations demonstrate that the phonetic basis of the contrast between class A and class B consonants is not one involving a contrast in voicing. Moreover, the two classes of consonants do not differ substantially in their temporal properties.

This chapter investigates the spectral characteristics of the class A and class B consonants as well as the vowels adjoining these consonants. In the first section the amplitude of the burst of the class A and class B stops, affricates, and lateral fricatives are examined. The amplitude of frication of the class A and class B affricates, fricatives, and h's are also examined. In the next three sections the formant frequencies and bandwidths, phonation quality, and fundamental frequency of the adjacent vowels are investigated. In contrast to the subtle temporal differences, there are robust differences in the amplitudes of the consonants and in the spectral characteristics of the adjacent vowels.

5.2. Amplitude

5.2.1. Introduction

Several aerodynamic and articulatory factors interact in determining the amplitude of the speech signal including subglottal air pressure, transglottal resistance, and supralaryngeal configuration. The factors which contribute to variation in amplitude in the speech signal have been examined in a number of theoretical and empirical studies (Isshiki and Ringel 1964, Isshiki 1965, 1969; Rubin et al. 1967, Rothenberg 1968, Bernthal and Beukelman 1977). Based on the findings of these studies, it is possible to infer differences in articulation from variation in amplitude associated with specific aspects of the production of the class A and class B consonants.

In the case of the stops and affricates, the release of the stop closure produces a sudden onset of broad-spectrum noise referred to as the burst. Figure 5.1. illustrates a burst for the class A stop [t]. At the point in time of the stop release, the intraoral air pressure is greater than atmospheric air pressure; consequently, there is a rapid flow of air at release as the pressure differential is equalized. All else being equal, the amplitude of the burst is determined by the intraoral air pressure at the time of release and the degree of oral aperture (Malécot 1969, Brown and McGlone 1974, Ringel et al. 1967, Stevens 1971). Thus, it is possible to infer differences in intraoral air pressure from differences in the amplitude of the burst.

The amplitude of voiceless frication is determined by the volume of air flow. The volume of air flow, in turn, is determined by several factors including glottal aperture and subglottal air pressure. A greater volume of air flow resulting from a more open glottis could be inferred from greater amplitude. Thus, for affricate releases, fricatives, and class A [h] and class B [ɦ], the amplitude of voiceless frication provides an indirect measure of differences in air flow and glottal aperture.

In this section the amplitude of the bursts of the stops and affricates and the voiceless frication of the affricate releases, fricatives, and h's are investigated. The inferences about the production of the contrast which can be drawn from variation in amplitude will be discussed.

5.2.2. Procedure

Amplitude was measured from an energy display on CSL with reference to simultaneously displayed, time-aligned waveform and wideband spectrogram (bandwidth of 586 Hz) displays. The amplitude information in the energy display was averaged over unsmoothed 5 ms windows with time advances of 1 ms which enabled the display to resolve subtle increments and decrements in energy.

The maximum amplitude of the burst for the class A and class B stops and affricates as well as the maximum amplitude of the affricate release were measured. For the fricatives, the maximum amplitude of frication in voiceless fricatives without intermittent voicing was measured. The fricative data of speaker EF was excluded due to the prevalence of voicing and intermittent voicing in the tokens. A substantial number of the lateral fricatives were produced with an identifiable burst coinciding with the release of the central closure. The maximum amplitude of the burst for these fricatives was measured. Figure 5.1 and 5.2 illustrate bursts for the class A stop [t] and class A lateral fricative [ɬ].

For class A [h] and class B [ɦ], the maximum amplitude of frication in voiceless [h] and [ɦ] which did not exhibit intermittent voicing was measured. The data were limited to speakers JO, AV, and PA due to the prevalence of voicing and intermittent voicing for the other speakers.

Figure 5.1. Example of burst for the class A stop [t] from time-aligned waveform and spectrogram displays. The burst is indicated by markers in the waveform display and by arrows in the spectrogram.

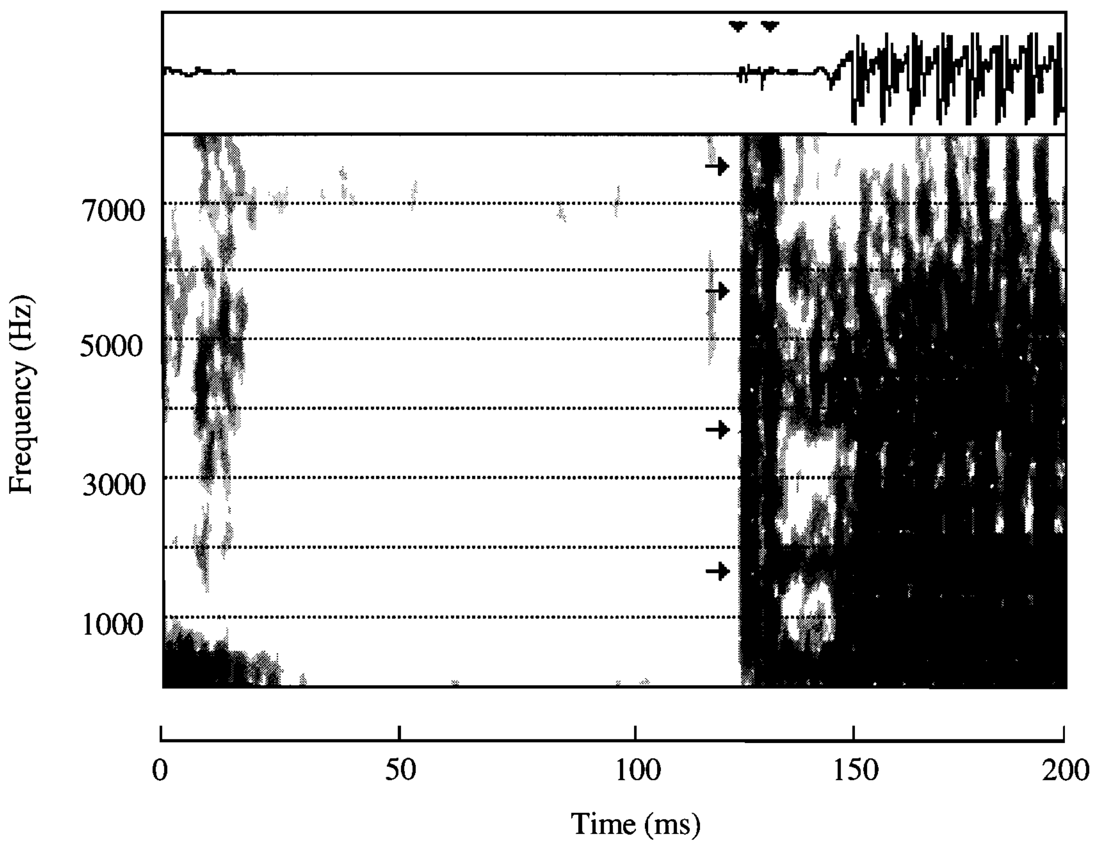
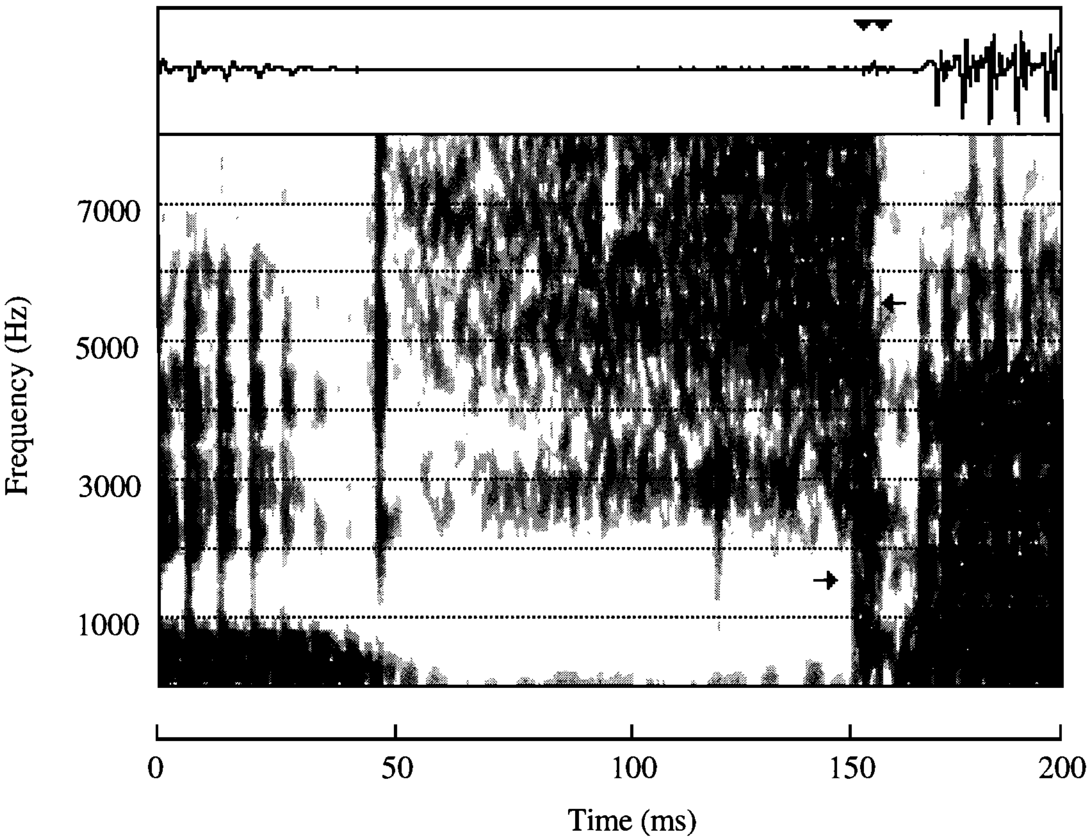


Figure 5.2. Example of burst for the class A lateral fricative [ɬ] from time-aligned waveform and spectrogram displays. The burst is indicated by markers in the waveform display and by arrows in the spectrogram.



For all of the measurements described above, the maximum amplitude of the following vowel [a] was measured as well. The difference between the maximum amplitude of the vowel and the relevant amplitude measurements for the class A and class B consonants was calculated in order to normalize for individual speakers' amplitude (Fischer-Jørgensen 1968, Zue 1980). In the following section the normalized amplitude measurements are presented for the class A and class B consonants.

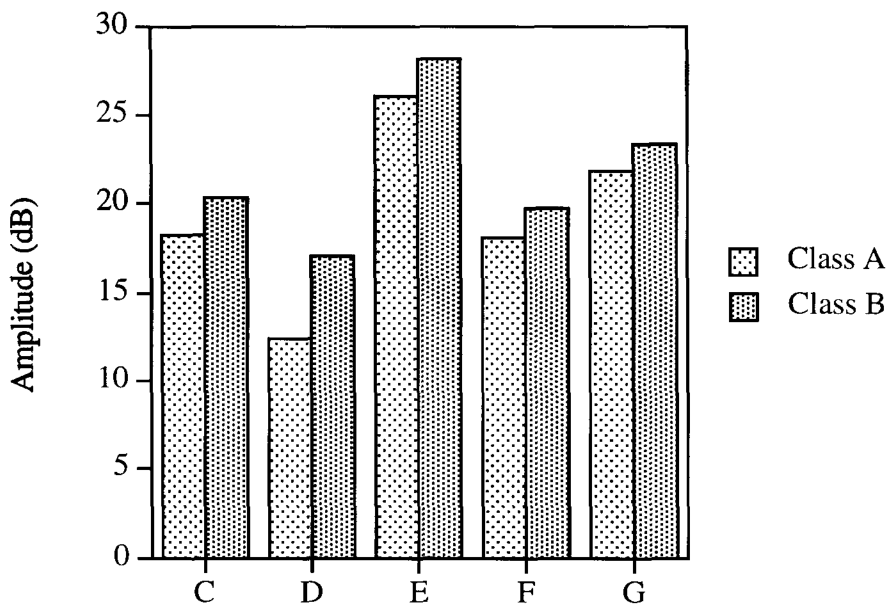
The statistical findings presented in this section were obtained with a three-factor ANOVA performed on the amplitude measurements in order to test for significant effects of consonant class, place of articulation, and speaker identity. Individual two-factor ANOVA's were performed for each place of articulation as well. Post-hoc comparisons of means were then conducted for each pairwise comparison of place of articulation with the Spjotvoll and Stoline test (SST) to determine whether the means for the separate places of articulation were distinct.

In order to determine the effect of tone on the amplitude measurements, a three-factor ANOVA with tone, consonant class, and speaker as main effects was performed for each amplitude measurement for the class A and class B consonants. Tone does not have a significant effect on the amplitude of the class A and class B consonants.

5.2.3. Results

The class A consonants have a greater amplitude for the five amplitude measurements investigated as indicated by the lower mean difference. The mean vowel-consonant amplitude differences are presented in Figure 5.3.

Figure 5.3. Mean difference in amplitude (dB) for the burst of the class A and class B stops and affricates (C), the release frication of the class A and class B affricates (D), the frication of the class A and class B fricatives (E), the burst of the class A and class B lateral fricatives (F), and the frication of the class A [h] and class B [ɦ] (G).



In the remainder of this section these results are discussed in more detail.

5.2.3.1. Stops and affricates

5.2.3.1.1. Amplitude of the burst

The bursts of the class A stops and affricates are stronger than those of the class B stops and affricates as indicated by the lower mean vowel-burst difference for class A ($F[1,1127]=133.37$, $p<.0001$). The mean amplitude of the vowel-burst differences are shown in Table 5.1.

The effect of place of articulation is significant ($F[3,1127]=2023.61$, $p<.0001$). The labial stops have the greatest vowel-burst difference indicating that they have the lowest amplitude of the stops. The alveolar and velar stops have greater burst amplitudes than the labials but are not significantly distinct as indicated by post-hoc comparisons between means with the SST. Finally, the burst amplitudes are lower for the affricates than any of the stops. The significantly lower burst amplitudes of the affricates may result from the release of the affricate closure into a fricative stricture and/or the shorter closure duration of the affricates producing lower peak intraoral pressure.

Table 5.1. Mean amplitude of vowel-burst difference (dB) for class A and class B stops and affricates according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	14.0	6.2	146	96.45	.0001
b	18.3	6.4	153		
t	10.8	5.0	149	61.46	.0001
d	14.1	6.2	148		
tʃ	36.5	6.3	152	9.35	.0024
dʒ	38.3	5.8	140		
k	11.2	5.6	152	8.25	.0044
g	11.9	6.3	151		
$\bar{x}_A$	18.2	12.2	599	133.37	.0001
$\bar{x}_B$	20.4	12.0	592		

5.2.3.1.2. Amplitude of frication of affricates

The mean amplitude of vowel-frication of the class B affricates is 4.6 dB greater than the class A affricates ($F[1,276]=99.15$, $p<.0001$) as seen in Table 5.2.

Table 5.2. Mean amplitude of vowel-frication difference (dB) for class A and class B affricates.

	Mean	Std. Dev.	n	F-value	P-value
tʃ	12.4	4.5	152	99.15	.0001
dʒ	17.0	4.5	140		

5.2.3.2. Fricatives

The class B fricatives have a significantly greater vowel-frication difference than the class A fricatives ($F[1,388]=63.72$, $p<.0001$) indicating that the amplitude of the frication of the class B fricatives is weaker. The difference of the amplitude of vowel-frication appear in Table 5.3.

There is a significant main effect of place ($F[2,388]=390.41$, $p<.0001$). The labial and lateral fricatives are not distinct in the difference of vowel-frication as indicated by the SST. For the sibilants, though, the difference is significantly smaller, indicating that the sibilants are produced with greater amplitude relative to the amplitude of the following vowel than the non-sibilant fricatives. These findings are consistent with the findings of previous studies on relative amplitudes of fricatives at differing places of articulation (Behrens and Blumstein 1988, Stevens 1971, Strevens 1960).

Table 5.3. Mean difference of the amplitude (dB) of vowel-frication for class A and class B fricatives according to place of articulation and consonant class. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	26.2	3.1	57	43.68	.0001
v	30.0	4.7	95		
s	20.5	3.4	38	11.46	.0011
z	22.7	3.6	50		
ɬ	28.4	6.0	87	25.00	.0001
ɮ	29.4	6.1	95		
$\bar{x}_A$	26.0	5.6	182	63.72	.0001
$\bar{x}_B$	28.2	5.8	240		

The class A lateral fricatives have a greater burst amplitude than the class B lateral fricatives as indicated by the lower amplitude of vowel-burst for class A ($F[1,168]=16.14$, $p<.0001$). The mean vowel-burst amplitudes appear in Table 5.4.

Table 5.4. Amplitude of vowel-burst (dB) for class A and class B lateral fricatives.

	Mean	Std. Dev.	n	F-value	P-value
ɬ	18.1	6.5	87	16.14	.0001
ɮ	19.7	5.8	90		

5.2.3.3. Class A [h] and class B[ɦ]

The vowel-frication difference is 1.4 dB greater for the class B [ɦ] than for the class A [h] ($F[1,29]=7.01$, $p<.0130$) as shown in Table 5.5.

Table 5.5. Mean difference of the amplitude of vowel-h (dB) for class A [h] and class B[ɦ].

	Mean	Std. Dev.	n	F-value	P-value
h	21.9	4.5	26	7.01	.0130
ɦ	23.3	6.1	9		

5.2.4. Discussion

The class A consonants have a greater amplitude than the class B consonants. The class A stops and affricates exhibit a greater burst amplitude than the class B stops and affricates as indicated by the significantly lower vowel-burst difference. Greater intraoral pressure at release can be inferred from the greater amplitude of the bursts of the class A stops and affricates. A difference in intraoral air pressure may indicate variation in one or more of the following: subglottal air pressure, glottal aperture, supralaryngeal cavity size, and cavity wall compliance (Rothenberg 1968, Müller and Brown 1980, Westbury 1983).

The peak amplitude of the frication of the class A affricates, fricatives, and the class A [h] is significantly greater than the peak amplitude of the class B affricates, fricatives, and the class B [ɦ]. These differences in amplitude may indicate a difference in glottal aperture with the class A consonants exhibiting a larger glottal aperture and a greater air flow resulting in greater peak amplitude. The greater burst amplitude of the class A lateral fricatives may also indicate a larger glottal aperture for the class A fricatives.

In Chapter 6, these inferences about the phonetic basis of the contrast will be considered in conjunction with the inferences drawn from the other acoustic properties of these consonants.

5.3. Formant frequency and bandwidth

5.3.1. Introduction

The frequency and bandwidth of the formants of a vowel allow inferences about two separate articulatory characteristics of the supralaryngeal cavity during the production of the vowel. Some aspects of the shape and size of the vocal tract can be inferred from the frequencies of the formants (Fant 1960, 1965). In addition, the bandwidths of the formants indicate the rate of energy loss in the vocal tract (Fant 1960, 1962; Fujimura and Lindqvist 1971). Thus, the bandwidths of the formants enable inferences about differences in glottal resistance and the resistance of the vocal tract walls.

In this section the formant frequences of the first three formants of the vowel [a] are investigated shortly after the release of class A and class B consonants in order to infer whether differences in the supralaryngeal cavity exist during the production of these consonant classes. The bandwidths of the first five formants of the vowel are also investigated. The inferences about the production of the contrast which can be drawn from these measures of the vowel formants will be discussed.

5.3.2. Procedure

The class A and class B consonants were examined referring to a wideband spectrogram (bandwidths of 586 Hz) with a simultaneously displayed, time-aligned waveform display. LPC was computed with a frame length of 12.5 ms in the vowel [a]. The analysis window was positioned 10 ms from the onset of the vowel. The consonant preceding the vowel [a] was limited to the set [t, d, s, z, h, ɦ]. The frequencies of the first three formants were measured. The bandwidths of the first five formants were measured. Bandwidth measurements greater than 900 Hz were excluded from the data set.

The statistical findings presented below were obtained with a two-factor ANOVA performed on the frequency and bandwidth measurements in order to test for significant effects of consonant class and speaker identity.

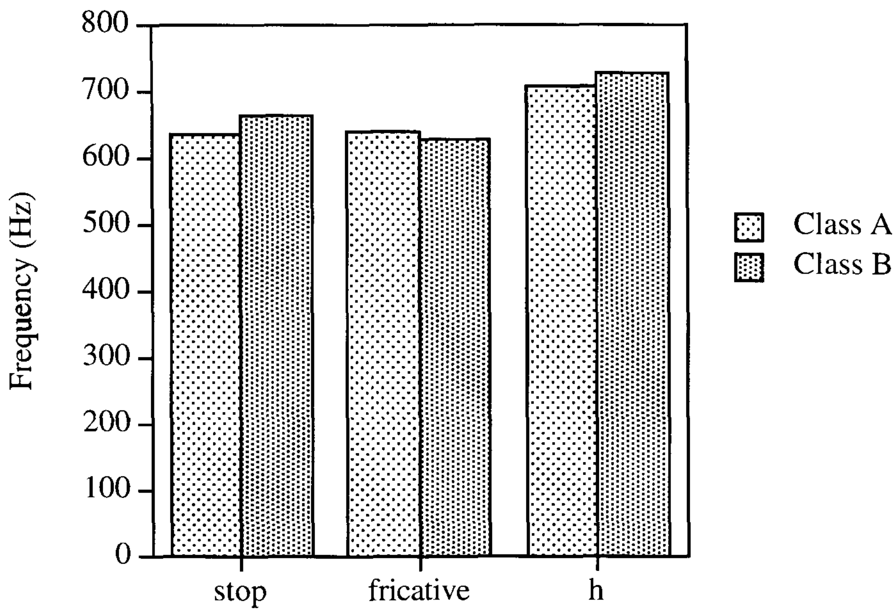
In order to determine the effect of tone on the these measurements, a three-factor ANOVA with tone, consonant class, and speaker as main effects was performed for the frequency and bandwidth measurement for the class A and class B consonants. Tone has a significant effect on the frequency and bandwidth of the class A and class B consonants.

5.3.3. Results

5.3.3.1. Formant frequency

The first formant (F1) of the vowel following the class B stop and class B [ɦ] is significantly higher than the F1 of the vowel following the class A stop and class A [h], respectively. The frequency of F1 is not affected by the consonant class of the preceding fricative as seen in Figure 5.4. The class of the preceding consonant does not influence the frequency of the second (F2) and third (F3) formants. In the remainder of this section these results are discussed in more detail.

Figure 5.4. Mean F1 (Hz) for class A and class B stops, fricatives, and h's.



5.3.3.1.1. Stops

The frequency of F1 is 27 Hz higher in the vowel following the class B [d] than in the vowel following the class A [t] ($F[1,239]=8.83$, $p<.0033$). The formant frequencies of F2 and F3 are not significantly different in the vowels following the class A [t] and class B [d]. These findings are presented below in Table 5.6.

A significant main effect of speaker and a significant interaction with consonant class occur. Examination of the individual speakers reveals that the frequency of F1 is significantly higher in the vowel following the class B [d] for speakers JO, EL, and PA. There is no difference for speakers AK, EF, TA, and BE. For speaker AV, on the other hand, F1 is significantly lower in the vowel following the class B stop. Thus, the difference in F1 is great enough for speakers JO, EL, and PA that it dominates the group means. However, the inter-speaker differences indicate that lower F1 is not a reliable characteristic of class B.

Table 5.6. Mean frequency (Hz) of the first three formants at the onset of [a] following the class A [t] and class B [d].

		Mean	Std. Dev.	n	F-value	P-value
F1	t	636	90	124	8.83	.0033
	d	663	68	131		
F2	t	1665	140	124	2.75	.0988
	d	1699	161	136		
F3	t	2873	197	127	1.03	.3121
	d	2878	205	130		

The tone of [a] has a significant effect on the frequency of F1 as determined by an ANOVA with the factors consonant class, tone, and speaker ($F[1,223]=20.01$, $p<.0001$). F1 is significantly higher by 14 Hz with [á] than with [ā].

5.3.3.1.2. Fricatives

The formant frequencies of F1 through F3 are not significantly different in the vowels following the class A [s] and class B [z] as seen in Table 5.7.

Table 5.7. Mean frequency (Hz) of the first three formants at the onset of [a] following the class A [s] and class B [z].

		Mean	Std. Dev.	n	F-value	P-value
F1	s	639	76	137	1.87	.1725
	z	627	78	138		
F2	s	1657	160	137	3.65	.0573
	z	1674	160	140		
F3	s	2863	319	141	0.01	.9409
	z	2854	245	141		

5.3.3.1.3. Class A [h] and Class B [ɦ]

The frequency of F1 is 21 Hz higher in the vowel following the class B [ɦ] than in the vowel following the class A [h] ($F[1,197]=9.15$, $p<.0028$). The frequency of F3 is 52 Hz higher in the vowel following the class A [h] than in the vowel following the class B [ɦ] ($F[1,204]=6.59$, $p<.0110$) The frequency of F2 is not significantly different in the vowels following the class A [h] and class B [ɦ] as seen in Table 5.8.

Table 5.8. Mean frequency (Hz) of the first three formants at the onset of [a] following the class A [h] and class B [ɦ].

	Mean	Std. Dev.	n	F-value	P-value
F1 h	707	83	110	9.15	.0028
ɦ	728	106	103		
F2 h	1630	180	111	0.01	.9353
ɦ	1648	173	105		
F3 h	2891	292	116	6.59	.0110
ɦ	2839	241	104		

A significant main effect of speaker and a significant interaction with consonant class occur. Examination of the individual speakers reveals that the frequency of F1 is significantly higher in the vowel following the class B [ɦ] for speakers EL, TA, and BE. There is no difference for speakers JO, EF, and TA. For speaker AV, on the other hand, F1 is significantly lower in the vowel following the class B stop. The difference in F1 is great enough for speakers EL, TA, and BE that it dominates the group means.

The tone of the vowel [a] has a significant effect on the frequency of F3 as determined by an analysis of variance with the factors consonant class, tone, and speaker (F[1,188]=5.37, p<.0216). F3 is significantly higher by 33 Hz with [á] than with [ā].

5.3.3.2. Formant bandwidth

The bandwidth of F1 in the vowel following the class A stop is significantly greater than the bandwidth in the vowel following the class B stop. There is a tendency for the bandwidth of F1 to be greater in the vowel following the class A fricative; however, it is not significant. The bandwidth of F1 is not affected by the consonant class of the preceding h. The bandwidth of F4 is greater with the class B stop and fricative; the bandwidth of F4 is greater in the vowel following the class B [ɦ], but the difference is not significant. These results are summarized in Figure 5.5. The consonant class of the preceding consonant does not influence the bandwidths of F2 and F3. In the remainder of this section these results are discussed in more detail.

5.3.3.2.1. Stops

The bandwidth of F1 is 25 Hz greater in the vowel following the class A [t] than in the vowel following the class B [d] (F[1,229]=38.83, p<.0001). In a similar manner, the bandwidths of F2 and F3 are 27 and 75 Hz greater, respectively, in the vowel following the class A [t] than in the vowel following the class B [d], (F[1,239]=8.52, p<.0039) and (F[1,228]=16.75, p<.0001), respectively. However, the bandwidth of F4 is 64 Hz greater in the vowel following the class B [d] than in the vowel following the class A [t] (F[1,201]=14.01, p<.0002). The bandwidths of F5 are not significantly different in the vowels following the class A [t] and class B [d].

Figure 5.5. Mean bandwidths (Hz) for F1 and F4 at the onset of the vowel [a] for the class A and class B stops, fricatives, and h's.

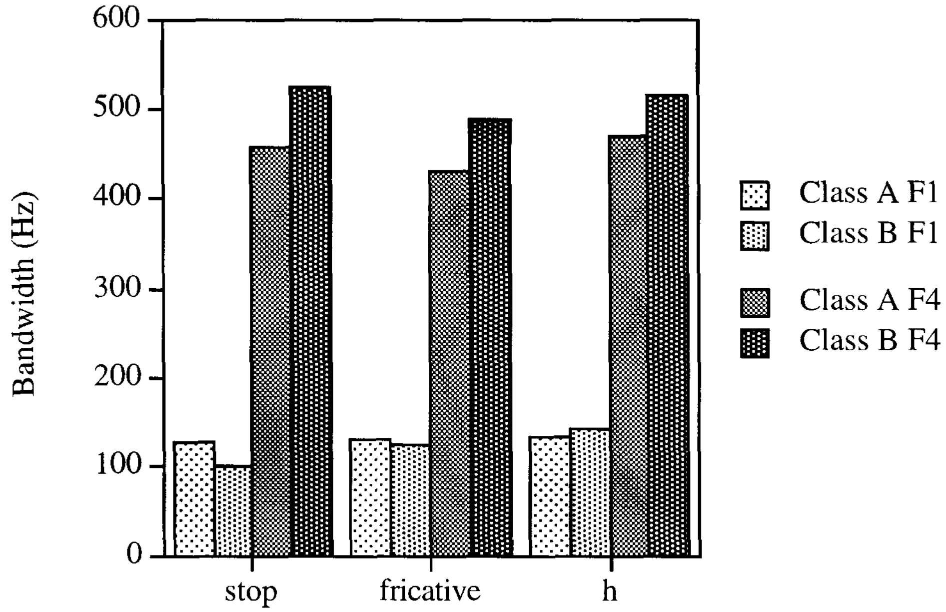


Table 5.9. Mean bandwidth (Hz) of the first five formants at the onset of [a] following the class A [t] and class B [d].

		Mean	Std. Dev.	n	F-value	P-value
F1	t	127	49	119	38.83	.0001
	d	102	37	126		
F2	t	345	148	121	8.52	.0039
	d	318	149	134		
F3	t	442	160	123	16.75	.0001
	d	367	168	121		
F4	t	459	170	108	14.01	.0002
	d	523	193	109		
F5	t	596	172	73	0.03	.8679
	d	582	168	86		

A significant main effect of speaker and a significant interaction with consonant class occur. Examination of the individual speakers reveals that the bandwidth of F1 is significantly greater in the vowel following the class A [t] for all the speakers except TA. In the case of F2, the bandwidth is significantly greater in the vowel following the class A [t] for speakers AV, EL, BE, and TA but not the remaining. The bandwidth of F3 is significantly greater in the vowel following the class A [t] for all the speakers except PA and EF. Finally, speakers AV, AK, PA, and BE exhibit a significantly greater bandwidth for F4 but the remaining speakers do not.

The tone of the vowel has a significant effect on the bandwidth of F1 and F4 as determined by an analysis of variance with the factors consonant class, tone, and speaker, (F[1,213]=8.99, p<.0030) and (F[1,185]=9.16, p<.0028), respectively. F1 is significantly higher by 11 Hz with [ā] than with [á]. F4 is significantly higher with [á] than with [ā] by 65 Hz.

5.3.3.2.2. Fricatives

The bandwidth of F2 is 46 Hz greater in the vowel following the class A [s] than in the vowel following the class B [z] (F[1,251]=5.65, p<.0182). The bandwidth of F4 is 57 Hz greater in the vowel following the class B [z] than in the vowel following the class A [s] (F[1,220]=7.56, p<.0065) The bandwidths of F1, F3, and F5 are not significantly different in the vowels following the class A [s] and class B [z] as seen in Table 5.10.

Table 5.10. Mean bandwidth (Hz) of the first five formants at the onset of [a] following the class A [s] and class B [z].

		Mean	Std. Dev.	n	F-value	P-value
F1	s	132	55	130	2.51	.1142
	z	124	46	130		
F2	s	417	157	132	5.65	.0182
	z	371	165	135		
F3	s	422	174	133	0.07	.7887
	z	425	178	132		
F4	s	431	198	120	7.56	.0065
	z	488	212	116		
F5	s	590	167	77	0.52	.4726
	z	631	166	98		

Examination of the individual speakers reveals that the bandwidth of F2 is significantly greater in the vowel following the class A [s] for AV, PA, and EF. The bandwidth of F2 is smaller in the vowel following the class A fricative for speakers AK and BE and no significantly different in the remaining speakers. In the case of F4, the bandwidth is significantly greater in the vowel following the class A [s] for speakers AV, AK, PA, and BE but not the remaining.

The tone of the vowel has a significant effect on the bandwidth of F3 as determined by an analysis of variance with the factors consonant class, tone, and speaker (F[1,233]=6.26, p<.0130). F3 is significantly higher with [á] than with [ā] by 35 Hz.

5.3.3.2.3. Class A [h] and Class B [ɦ]

The bandwidth of F3 is 64 Hz greater in the vowel following the class B [ɦ] than the class A [h] (F[1,169]=7.47, p<.0070). The bandwidths of the remaining formants are not significantly different in the vowels following the class A [h] and class B [ɦ] as seen in Table 5.11.

Table 5.11. Mean bandwidth (Hz) of the first five formants at the onset of [a] following the class A [h] and class B [ɦ].

		Mean	Std. Dev.	n	F-value	P-value
F1	h	133	68	102	0.09	.7649
	ɦ	142	57	98		
F2	h	401	175	106	0.12	.7259
	ɦ	396	214	91		
F3	h	422	188	101	7.47	.0070
	ɦ	486	204	84		
F4	h	470	201	71	1.24	.2673
	ɦ	516	190	80		
F5	h	579	180	75	0.24	.6280
	ɦ	591	186	73		

A significant main effect of speaker and a significant interaction with consonant class occur. Examination of the individual speakers reveals that the bandwidth of F3 is significantly greater in the vowel following the class B [ɦ] for speakers AV, EF, and TA but not the remaining speakers.

5.3.4. Discussion

Differences in the shape and size of the vocal tract can be inferred from the frequencies of the formants. There is a tendency for the frequency of F1 in the vowel following the class B consonants to be higher for some speakers than in the vowel following the class A consonants. These differences in formant frequency indicate that the class B consonants are produced with a smaller supralaryngeal cavity than the class A consonants by these speakers. However, there are substantial inter-speaker differences which suggest that the inferred differences in supralaryngeal cavity size represent different production strategies employed by the speakers. Thus, the formant frequency differences do not generally characterize the difference between the two classes.

The bandwidths of the first two formants are significantly influenced by energy loss primarily due to glottal resistance (Fant 1960, 1965). The bandwidths of F3 through F5, on the other hand, indicate differences in energy loss primarily attributable to the compliance of the vocal tract walls. The bandwidths of F1 and F2 in the vowels following the class A obstruents tend to be greater for some of the speakers than in vowels following the class B obstruents. In the case of the class A [h] and class B [ɦ], though, there is no difference in the bandwidths of F1 and F2. The bandwidths of the vowels following the class A obstruents suggest that these consonants are produced with greater glottal aperture by some speakers. The bandwidth of F4 is greater in the vowels following the class B obstruents for some speakers which may indicate less supralaryngeal cavity wall compliance for the class B obstruents. In the case of each formant, there are inter-speaker differences which suggest that the inferred differences in glottal configuration and vocal tract wall compliance represent different production strategies by the speakers. However, these differences do not consistently distinguish the classes.

These inferences about the phonetic differences between the class A and class B consonants will be considered in conjunction with the inferences drawn from the other acoustic properties of these consonants in Chapter 6.

5.4. Phonation quality

5.4.1. Introduction

The laryngeal configuration of a consonant influences the phonation quality of adjacent vowels. Thus, it is possible to infer from differences in the phonation quality at the onset of the vowels following the class A and class B consonants aspects of the laryngeal configuration of these consonants. A standard means of investigating phonatory differences from an acoustic signal entails measuring the relative amplitudes of the first and the second harmonics. It has been shown that in breathy phonation the energy in the first harmonic relative to the higher harmonics is comparatively greater than is the case in modal or creaky phonation (Ladefoged 1981; Bickley 1982; Ladefoged et al. 1988).

5.4.2. Procedure

Power spectra of the vowels were calculated using an FFT analysis on CSL. These spectra were calculated with a 25.5 ms analysis window positioned to begin at the onset of periodicity in the vowel of the target syllable. The amplitude of the fundamental or first harmonic (H1) and second harmonic (H2) were measured from the display. Measurements were also taken at the middle and offset of the vowel. The amplitude of H1 and H2 was also measured at the offset of the preceding vowel [i]. In addition, for class A [h] and class B [ɦ], the amplitude of H1 and H2 were measured at the middle of those tokens of [h] and [ɦ] which were fully voiced. Speakers AV and PA did not produce tokens of [h] or [ɦ] which were fully voiced; consequently, data from these speakers were not included. The difference of H1-H2 was calculated; the H1-H2 difference is referred to here as 'spectral tilt'.

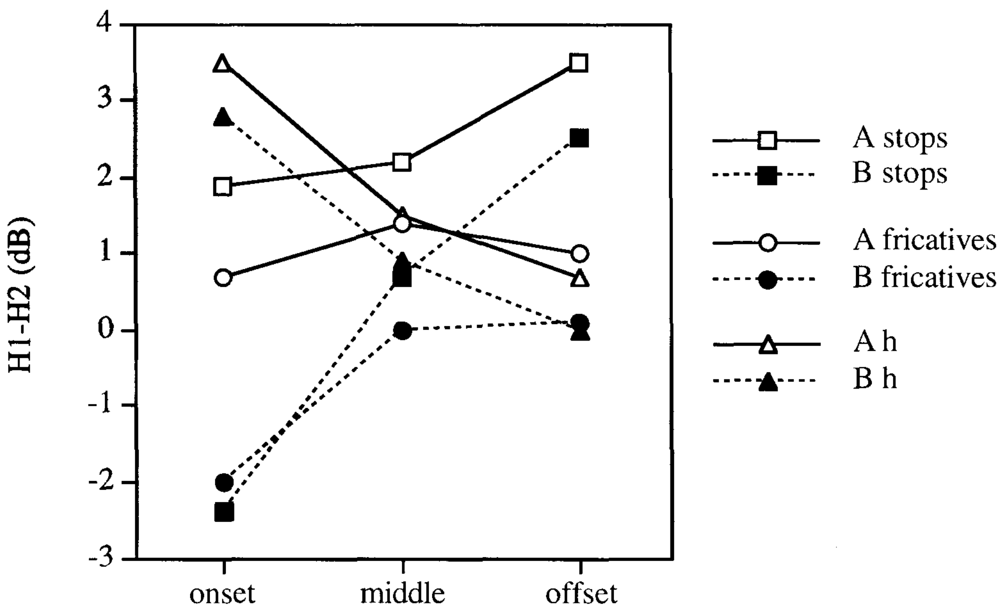
The statistical findings presented in this section were obtained with a three-factor ANOVA performed on the H1-H2 measurements in order to test for significant effects of consonant class, place of articulation, and speaker identity. Individual two-factor ANOVA's were performed for each place of articulation as well. Post-hoc comparisons of means were then conducted for each pairwise comparison of place of articulation with the Spjotvoll and Stoline test (SST).

In order to determine the effect of tone on spectral tilt, a three-factor ANOVA with tone, consonant class, and speaker as main effects was performed for each measurement for the class A and class B consonants. Tone does not have a significant effect on the spectral tilt of the class A and class B obstruents. In the case of class A [h] and class B [ɦ], though, tone has an effect on the H1-H2 difference as discussed below.

5.4.3. Results

The spectral tilt in the onset of the vowel [a] is greater after the class A consonants than after the class B consonants as seen in Figure 5.6. In the case of the obstruents, the difference in spectral tilt remains significant across the vowel but decreases in magnitude. The spectral tilt at the onset of the vowel following the class A [h] and class B [ɦ] is greater than found with the obstruents. Moreover, the magnitude of the difference between the spectral tilt in the vowels following [h] and [ɦ] remains relatively constant across the vowel. No reliable difference in spectral tilt was found in the vowel preceding the consonants.

Figure 5.6. Mean amplitude (dB) of the difference in H1-H2 at the onset, middle, and offset of [a] when preceded by class A and class B stops and affricates (squares), class A and class B fricatives (circles), and class A [h] and class B [ɦ] (triangles).



5.4.3.1. Stops and affricates

5.4.3.1.1. Phonatory characteristics of [a]

The spectral tilt is 4.3 dB greater after the class A stops and affricates than after the class B stops and affricates at the onset of the vowel [a] ($F[1,1146]=1301.68$, $p<.0001$). The spectral tilt remains greater after the class A stops and affricates through the remainder of the vowel as shown in Tables 5.12-14.

Place of articulation has a significant main effect on the spectral tilt in the onset of the vowel ($F[3,1146]=58.59$, $p<.0001$). The velar stops have a significantly greater H1-H2 difference than the labial and alveolar stops which are not significantly distinct themselves as indicated by post-hoc comparisons between means with the SST. The affricates have a substantially lower spectral tilt than the stops. The place category has a significant effect on the spectral tilt in the middle of the vowel ($F[3,1146]=18.09$, $p<.0001$) and at the offset ($F[3,1146]=389.47$, $p<.0001$). Any actual place effect at these points in the vowel is confounded with the effect of the different consonant types in coda position. Thus, nothing can be determined regarding this effect at the end of these syllables.

Table 5.12. Mean amplitude (dB) of the difference in H1-H2 in the onset of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	2.3	3.7	145	301.28	.0001
b	-2.4	2.4	153		
t	2.3	3.0	149	323.09	.0001
d	-2.2	2.2	149		
tʃ	0.0	3.6	152	219.88	.0001
dʒ	-3.1	2.9	160		
k	3.1	3.3	152	496.36	.0001
g	-1.8	2.3	150		
$\bar{x}_A$	1.9	3.6	598	1301.68	.0001
$\bar{x}_B$	-2.4	2.5	612		

Table 5.13. Mean amplitude (dB) of the difference in H1-H2 at the middle of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	2.5	3.9	145	23.77	.0001
b	1.4	2.7	153		
t	1.8	2.9	149	69.35	.0001
d	0.0	2.2	149		
tʃ	2.0	3.7	152	26.75	.0001
dʒ	0.6	2.7	160		
k	2.7	3.7	152	59.74	.0001
g	0.8	3.3	150		
$\bar{x}_A$	2.2	3.6	598	168.69	.0001
$\bar{x}_B$	0.7	2.8	612		

Table 5.14. Mean amplitude (dB) of the difference in H1-H2 at the offset of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	6.8	5.8	145	1.15	.2853
b	6.4	5.7	153		
t	0.8	2.8	149	43.15	.0001
d	-0.6	2.8	149		
tʃ	3.3	3.7	152	12.96	.0004
dʒ	2.2	3.6	160		
k	3.1	3.5	152	26.42	.0001
g	1.9	3.3	150		
$\bar{x}_A$	3.5	4.6	598	49.64	.0001
$\bar{x}_B$	2.5	4.7	612		

5.4.3.2. Fricatives

5.4.3.2.1. Phonatory characteristics of [a]

The spectral tilt is 2.7 dB greater after the class A fricatives than after the class B fricatives at the onset of the vowel [a] ($F[1,858]=448.73$, $p<.0001$). The difference in spectral tilt remains greater after class A fricatives through the remainder of the vowel as shown in Tables 5.15-17.

Table 5.15. Mean amplitude (dB) of the difference in H1-H2 in the onset of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	1.1	2.9	147	201.10	.0001
v	-2.2	3.4	155		
s	.3	3.4	151	160.21	.0001
z	-2.4	2.3	155		
ɬ	.8	4.1	143	98.31	.0001
ɮ	-1.6	2.4	155		
$\bar{x}_A$	.7	3.5	441	448.73	.0001
$\bar{x}_B$	-2.0	2.8	465		

Table 5.16. Mean amplitude (dB) of the difference in H1-H2 at the middle of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	1.5	3.4	129	13.25	.0003
v	0.5	4.5	154		
s	1.5	3.0	151	42.26	.0001
z	-0.5	2.9	137		
ɬ	1.1	3.1	127	10.15	.0016
ɮ	0.1	3.5	136		
$\bar{x}_A$	1.4	3.2	407	40.00	.0001
$\bar{x}_B$	0.0	3.7	427		

Table 5.17. Mean amplitude (dB) of the difference in H1-H2 at the offset of [a] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	1.4	3.4	129	10.95	.0011
v	0.7	2.8	154		
s	1.1	3.1	151	13.11	.0003
z	-0.5	2.9	137		
ɬ	0.5	3.8	127	4.26	.0400
ɮ	-0.1	2.9	136		
$\bar{x}_A$	1.0	3.4	407	22.25	.0001
$\bar{x}_B$	0.1	2.9	427		

Place of articulation has a significant main effect on the spectral tilt in the onset of the vowel ($F[1,858]=9.99$, $p<.0001$). The sibilant fricatives have a significantly smaller spectral tilt difference than the labial and lateral fricatives which are not themselves distinct as determined with the SST. Place does not have a significant effect on the spectral tilt in the middle of the vowel ($F[1,788]=.28$, $p<.7548$). At the offset, though, the place effect is significant ($F[1,788]=5.57$, $p<.0040$); the labial fricatives have a greater spectral tilt than the labial and sibilant fricatives which are not distinct.

5.4.3.3. Class A [h] and class B [ɦ]

5.4.3.3.1. Phonatory characteristics of [h] and [ɦ]

The spectral tilt is 1.7 dB greater for the voiced portion of class A [h] than for class B[ɦ] (F[1,150]=4.92, p<.0280) as shown in Table 5.18.

Table 5.18. Mean difference in amplitude (dB) of the difference in H1-H2 at the middle of voiced [h] and [ɦ].

	Mean	Std. Dev.	n	F-value	P-value
h	14.3	5.1	66	4.92	.0280
ɦ	12.6	6.4	96		

5.4.3.3.2. Phonatory characteristics of [a]

The spectral tilt is 0.7 dB greater after the class A [h] than after the class B [ɦ] at the onset of the vowel [a] (F[1,270]=4.50, p<.0348). At the middle of [a] the spectral tilt decreases to 0.6 dB and is not statistically significant. At the offset of the vowel the spectral tilt is 0.7 dB greater after the class A [h] than after the class B [ɦ] (F[1,256]=7.13, p<.0080) These findings are summarized in Tables 5.19-21.

Table 5.19. Mean amplitude (dB) of the difference in H1-H2 at the onset of [a] according to the class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	3.5	3.5	147	4.50	.0348
ɦ	2.8	3.5	139		

Table 5.20. Mean amplitude (dB) of the difference in H1-H2 at the middle of [a] according to the class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	1.5	3.0	146	3.51	.0620
ɦ	0.9	4.3	126		

Table 5.21. Mean amplitude (dB) of the difference in H1-H2 at the offset of [a] according to the class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	0.7	2.3	146	7.13	.0080
ɦ	0.0	3.0	126		

The tone of the syllable has a significant effect on the difference in H1-H2 at the middle of the vowel [a] as determined by an analysis of variance with the factors consonant class, tone, and speaker (F[1,241]=9.76, p<.0020). The difference in H1-H2 at the middle of the vowel [a] is significantly higher by 0.8 Hz with [á] than with [ā].

5.4.4. Discussion

The vowel following the class A consonants has greater amplitude for H1 relative to H2 than the vowel following the class B consonants, indicating a difference in spectral tilt. The difference in spectral tilt associated with the class A and class B consonants suggests that the vowel following a class A consonant is produced with a relatively greater glottal aperture. That is to say, the vowels are produced with a greater open quotient, the ratio of the open phase to the total duration of the pitch period. The difference in spectral tilt between the class A and class B obstruents is greatest at the onset of the vowel and progressively decreases across the vowel. This declination suggests that the difference in phonation quality of these vowels is attributable to the consonant and is not a property inherent to the vowel. The difference in glottal aperture inferred for the class A and class B consonants is confirmed in the case of the class A [h] and class B [ɦ]. The class A [h] has a greater spectral tilt than the class B [ɦ] as determined by measurements at the middle of these consonants. In addition, a difference in the mean difference of H1-H2 also occurs at the onset of the following vowel for the class A [h] and class B [ɦ].

In Chapter 6 these inferences about the phonetic basis of the contrast will be considered in light of the inferences drawn from the other acoustic properties of these consonants.

5.5. Fundamental frequency

5.5.1. Introduction

The laryngeal configuration of a consonant influences the spectral properties of adjacent vowels. The effect of various laryngeal configurations of obstruents on the fundamental frequency (F0) of a following vowel has been well documented. The F0 at the onset of the vowel following a voiceless consonant is higher than the onset F0 following a voiced consonant (House and Fairbanks 1953, Mohr 1971, Hombert 1978, Maddieson 1984, Ohde 1984, Silverman 1986).

It is possible to make inferences about differences in the laryngeal configuration of the class A and class B consonants from differences in F0 at the onset of the vowels following these consonants. In this section the F0 of the vowels preceding and following the class A and class B consonants are investigated. The inferences about the production of the contrast which can be drawn from the differences in F0 will be discussed.

5.5.2. Procedure

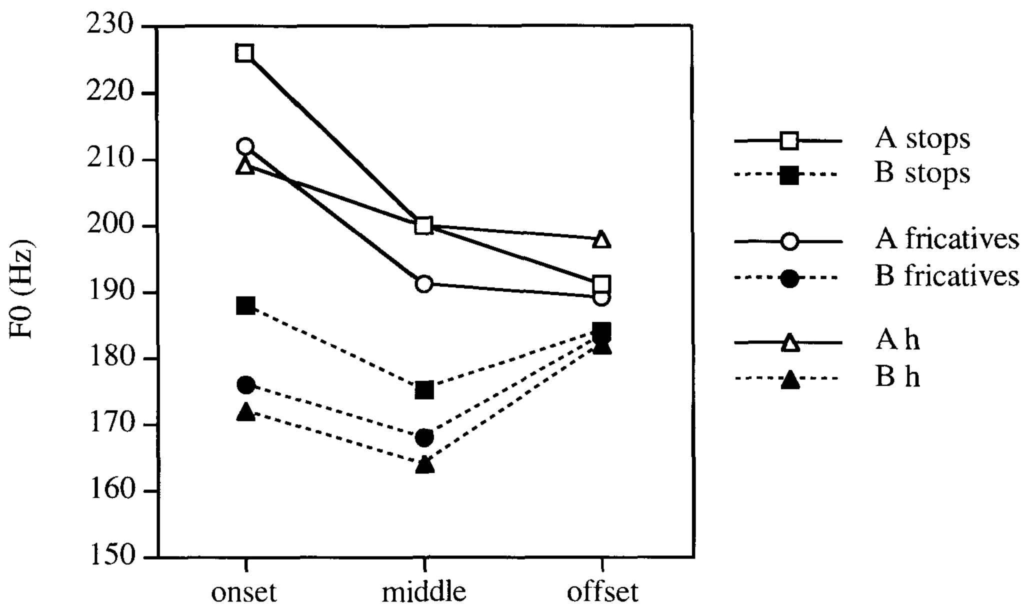
The fundamental frequency (F0) of the vowels adjoining the class A and class B consonants was calculated by measuring and averaging the duration of two adjacent pitch periods. This procedure minimized the confounding effect of pitch jitter. These measurements were made at the onset, middle, and offset of the vowel [a] of the target syllable and at the offset of the vowel [i] of the preceding syllable.

The statistical findings presented in this section were obtained with a three-factor ANOVA performed on the F0 measurements in order to test for significant effects of consonant class, place of articulation, and speaker identity. Individual two-factor ANOVA's were performed for each place of articulation as well. Post-hoc comparisons of means were then conducted for each pairwise comparison of place of articulation with the Spjotvoll and Stoline test (SST) to determine whether the means for the separate places of articulation were distinct.

5.5.3. Results

The F0 in the onset of the vowel [a] is greater after the class A consonants than after the class B consonants as seen in Figure 5.7 for the high-toned vowel [á] and in Figure 5.8. for the mid-toned vowel [ā]. The difference in F0 remains significant across the vowel but decreases in magnitude. No reliable difference in F0 was found in the vowel preceding the class A and class B consonants.

Figure 5.7. Mean F0 (Hz) of high-toned [á] at the onset, middle, and offset of the vowel when preceded by class A and class B stops and affricates (squares), class A and class B fricatives (circles), and class A [h] and class B [ɦ] (triangles).



5.5.3.1. Stops and affricates

5.5.3.1.1. Fundamental frequency of [á]

The F0 at the onset of the high-toned vowel [á] following the class A stops and affricates is 38 Hz higher than the onset F0 following the class B stops and affricates ($F[1,548]=909.79$, $p<.0001$). The F0 of [á] following the class A stops and affricates remained significantly higher than the F0 following the class B stops and affricates through the remainder of the vowel.

There is a significant effect of place on the onset F0 ($F[3,548]=20.73$, $p<.0001$). The onset F0 after the affricates is significantly higher than after the stops. The onset F0 after the velar stops is higher than the onset F0 after the labials but not the alveolars. The labials and alveolars are not distinct in their effect on the onset F0. Place has a significant effect on the F0 at the middle and the offset of the vowel, though the latter is confounded with the different coda consonants. These findings are summarized in Tables 5.22-24.

Figure 5.8. Mean F0 (Hz) of mid-toned [ā] at the onset, middle, and offset of the vowel when preceded by class A and class B stops and affricates (squares), class A and class B fricatives (circles), and class A [h] and class B [ɦ] (triangles).

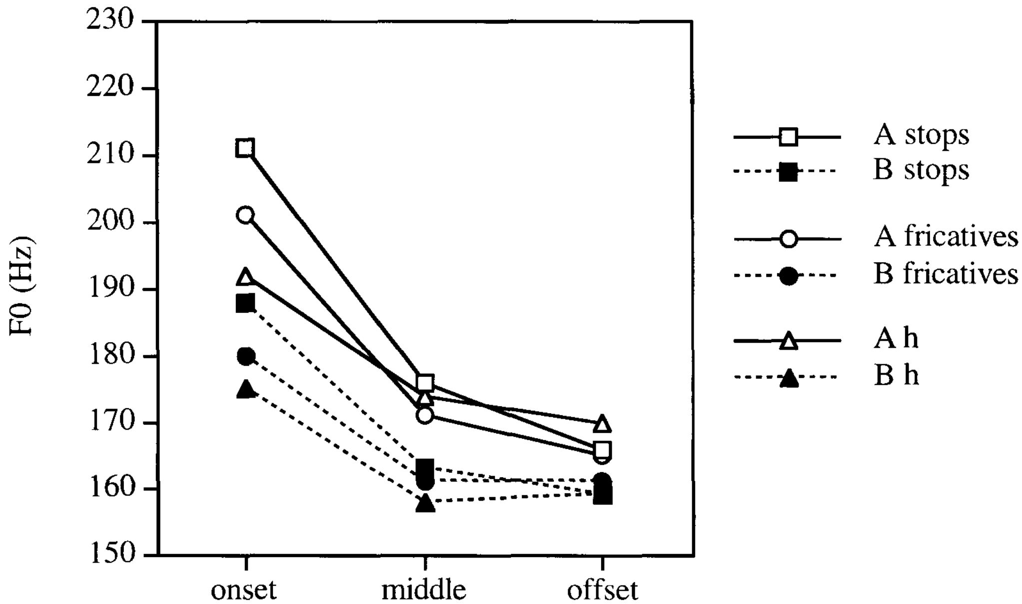


Table 5.22. Mean F0 (Hz) at the onset of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	218	41	70	177.73	.0001
b	185	40	78		
t	224	44	73	327.43	.0001
d	182	38	76		
tʃ	239	49	78	330.95	.0001
dʒ	191	41	83		
k	221	46	75	131.84	.0001
g	192	42	79		
$\bar{x}_A$	226	45	296	909.79	.0001
$\bar{x}_B$	188	40	316		

Table 5.23. Mean F0 (Hz) at the middle of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	199	35	70	115.56	.0001
b	183	43	78		
t	199	35	73	829.06	.0001
d	172	34	76		
tʃ	204	42	78	775.71	.0001
dʒ	172	36	83		
k	198	37	75	791.77	.0001
g	173	34	79		
$\bar{x}_A$	200	38	296	1841.91	.0001
$\bar{x}_B$	175	37	316		

Table 5.24. Mean F0 (Hz) at the offset of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	190	34	70	12.41	.0006
b	196	40	78		
t	190	32	73	22.98	.0001
d	182	38	76		
tʃ	194	40	78	93.26	.0001
dʒ	179	45	83		
k	189	35	75	58.90	.0001
g	181	38	79		
$\bar{x}_A$	191	35	296	69.48	.0001
$\bar{x}_B$	184	40	316		

5.5.3.1.2. Fundamental frequency of [ā]

The F0 at the onset of the mid-toned vowel [ā] following the class A stops and affricates is 23 Hz higher than the onset F0 following the class B stops and affricates ($F[1,532]=413.85$, $p<.0001$). The F0 of [ā] following the class A stops and affricates remained significantly higher than the F0 following the class B stops and affricates through the remainder of the vowel. There is a significant effect of place on the onset F0 ($F[3,532]=27.70$, $p<.0001$). The onset F0 after the affricates and velar stops is not significantly distinct as indicated by the SST; onset F0 after the affricates and velars is significantly higher than after the labial and alveolar stops. The onset F0 after the alveolar stops is, in turn, higher than the onset F0 after the labials. Place does not have a significant effect at the middle of the vowel (F[3,532]=1.52, p<.2095). Place has a significant effect on the F0 at the offset of the vowel (F[3,532]=6.74, p<.0002), although this is an artifact due to the different coda consonants. These findings are summarized in Tables 5.25-27.

Table 5.25. Mean F0 (Hz) at the onset of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	200	47	73	73.45	.0001
b	185	39	74		
t	209	49	76	142.77	.0001
d	186	41	73		
tʃ	221	51	73	149.48	.0001
dʒ	190	45	77		
k	213	52	78	67.47	.0001
g	193	45	72		
$\bar{x}_A$	211	50	300	413.85	.0001
$\bar{x}_B$	188	42	296		

Table 5.26. Mean F0 (Hz) at the middle of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	171	38	73	54.44	.0001
b	169	37	74		
t	175	38	76	269.33	.0001
d	161	32	73		
tʃ	179	42	73	82.77	.0001
dʒ	162	35	77		
k	177	39	78	238.53	.0001
g	162	34	72		
$\bar{x}_A$	176	39	300	526.45	.0001
$\bar{x}_B$	163	34	296		

Table 5.27. Mean F0 (Hz) at the offset of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
p	164	35	73	2.59	.1099
b	165	36	74		
t	166	32	76	50.05	.0001
d	157	32	73		
tʃ	168	37	73	25.87	.0001
dʒ	157	34	77		
k	165	35	78	56.17	.0001
g	156	34	72		
$\bar{x}_A$	166	34	300	103.99	.0001
$\bar{x}_B$	159	34	296		

5.5.3.2. Fricatives

5.5.3.2.1. Fundamental frequency of [á]

The F0 at the onset of the high-toned vowel [á] following the class A fricatives is 36 Hz higher than the onset F0 following the class B fricatives ($F[1,402]=1233.92$, $p<.0001$). The F0 of the high-toned vowel [á] following the class A fricatives is significantly higher through the remainder of the vowel. There is a significant effect of place on the onset F0 ($F[2,402]=9.11$, $p<.0001$). The onset F0 following the labial fricatives is significantly lower than the onset F0 following the lateral fricatives and sibilants which are not themselves distinct as determined with the SST. These findings are summarized in Tables 5.28-30.

Table 5.28. Mean F0 (Hz) at the onset of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	211	39	73	567.85	.0001
v	174	37	81		
s	213	45	76	435.70	.0001
z	177	36	76		
ɬ	213	44	69	284.01	.0001
ɮ	178	42	75		
$\bar{x}_A$	212	43	218	1233.92	.0001
$\bar{x}_B$	176	38	232		

Place has a significant effect at the middle of the vowel (F[2,402]=7.76, p<.0005) with vowels following the lateral fricatives exhibiting a lower F0 than following the labial fricatives and sibilants.

Table 5.29. Mean F0 (Hz) at the middle of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	189	37	65	315.33	.0001
v	172	36	80		
s	193	39	76	522.72	.0001
z	166	31	67		
ɬ	192	36	62	426.61	.0001
ɮ	165	36	66		
$\bar{x}_A$	191	37	203	935.56	.0001
$\bar{x}_B$	168	35	213		

Table 5.30. Mean F0 (Hz) at the offset of [á] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	187	37	65	.18	.6746
v	186	40	80		
s	190	39	76	18.29	.0001
z	184	41	67		
ɬ	191	39	62	54.12	.0001
ɮ	179	41	66		
$\bar{x}_A$	189	39	203	13.18	.0003
$\bar{x}_B$	183	40	213		

5.5.3.2.2 Fundamental frequency of [ā]

The F0 at the onset of the mid-toned vowel [ā] following the class A fricatives is 21 Hz higher than the onset F0 following the class B fricatives (F[1,408]=534.90, p<.0001). The F0 of the mid-toned vowel [ā] following the class A fricatives is significantly higher through the remainder of the vowel. There is a significant effect of place on the onset F0 (F[2,408]=9.14, p<.0001). The onset F0 following the lateral fricatives is significantly higher than the onset F0 following the labial fricatives and sibilants which are not themselves distinct as determined with the SST. The higher onset F0 following the lateral fricatives is due to the higher F0 after the class B lateral fricatives. These findings are summarized in the following Tables 5.31-33.

Table 5.31. Mean F0 (Hz) at the onset of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	201	44	74	244.19	.0001
v	176	40	74		
s	202	48	75	171.91	.0001
z	178	42	79		
ɬ	200	46	74	128.48	.0001
ɮ	186	45	80		
$\bar{x}_A$	201	46	223	534.90	.0001
$\bar{x}_B$	180	42	233		

Table 5.32. Mean F0 (Hz) at the middle of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	170	38	64	125.98	.0001
v	164	37	74		
s	174	37	75	274.24	.0001
z	156	34	70		
ɬ	168	36	65	75.05	.0001
ɮ	163	38	70		
$\bar{x}_A$	171	40	204	316.16	.0001
$\bar{x}_B$	161	36	214		

Table 5.33. Mean F0 (Hz) at the offset of [ā] according to the place of articulation and consonant class of the preceding consonant. F-values and P-values are presented for the separate pairwise A/B comparisons.

	Mean	Std. Dev.	n	F-value	P-value
f	162	32	63	3.54	.0622
v	165	37	74		
s	168	34	75	35.05	.0001
z	157	35	70		
ɬ	163	34	65	6.79	.0104
ɮ	162	37	70		
$\bar{x}_A$	165	34	203	16.70	.0001
$\bar{x}_B$	161	36	214		

5.5.3.3. Class A [h] and class B [ɦ]

5.5.3.3.1. Fundamental frequency of [á]

The F0 at the onset of the high-toned vowel [á] following the class A [h] is 37 Hz higher than the onset F0 following the class B [ɦ] ($F[1,130]=295.12$, $p<.0001$). The F0 of the high-toned vowel [á] following the class A [h] is significantly higher through the remainder of the vowel as shown in Tables 5.34-36.

Table 5.34. Mean F0 (Hz) at the onset of [á] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	209	**43**	74	295.12	.0001
ɦ	172	**42**	72		

Table 5.35. Mean F0 (Hz) at the middle of [á] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	200	**40**	74	455.36	.0001
ɦ	164	33	63		

Table 5.36. Mean F0 (Hz) at the offset of [á] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	198	41	74	41.65	.0001
ɦ	182	35	63		

5.5.3.3.2. Fundamental frequency of [ā]

The F0 at the onset of the mid-toned vowel [ā] following the class A [h] is significantly higher than the onset F0 following the class B [ɦ] ($F[1,125]=170.15$, $p<.0001$). The F0 of the mid-toned vowel [ā] following the class A [h] is significantly higher through the remainder of the vowel as shown in the following tables.

Table 5.37. Mean F0 (Hz) at the onset of [ā] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	192	45	73	170.15	.0001
ɦ	175	46	68		

Table 5.38. Mean F0 (Hz) at the middle of [ā] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	174	38	73	1063.33	.0001
ɦ	158	37	63		

Table 5.39. Mean F0 (Hz) at the offset of [ā] according to the consonant class of the preceding h.

	Mean	Std. Dev.	n	F-value	P-value
h	170	36	73	32.88	.0001
ɦ	159	36	63		

5.5.4. Discussion

The vowels following the class A consonants have a significantly higher F0 at the onset, middle, and offset than the vowels following the class B consonants. The difference between the mean F0 of the vowels following the class A and class B consonants is greatest at the onset of the vowel and progressively decreases across the vowel. The convergence of F0 across the vowel indicates that the difference in F0 is attributable to the consonant and is not an inherent characteristic of the vowel. In Chapter 6 the inferences which can be drawn from the differences in F0 will be considered in conjunction with the other acoustic properties of the class A and class B consonants.

5.6. Summary

The class A and class B consonants and the following vowel [a] exhibit significant differences in their spectral properties. In contrast to the small temporal differences reported in the preceding chapter, these differences are robust. The class A and class B consonants differ in the amplitude of the burst as well as peak amplitude of frication with the class A consonants produced with greater amplitude as indicated by a greater mean difference in amplitude between consonant and following vowel for the class B consonants. The onset of the vowel [a] exhibits greater spectral tilt and a higher F0 after the class A consonants than after the class B consonants. These principal spectral properties of the consonants are summarized in Table 5.40.

Table 5.40. Comparison of the properties of the class A and class B consonants including mean difference in burst amplitude for the stops, affricates, and lateral fricatives (B), mean difference in amplitude of frication for the affricates, fricatives, and h's (FR), spectral tilt as indicated by mean difference of H1-H2 at vowel onset (ST), and mean difference in F0 of [á] at vowel onset (F0).

	B	**FR**	ST	F0
Stops	2.8 dB greater with class B	**NA**	4.7 dB greater with class A	35 Hz higher with class A
Affricates	1.8 dB greater with class B	4.6 dB greater with class B	3.1 dB greater with class A	48 Hz higher with class A
Fricatives	1.6 dB greater with class B	2.2 dB greater with class B	2.7 dB greater with class A	36 Hz higher with class A
h	NA	1.4 dB greater with class B	0.7 dB greater with class A	37 Hz higher with class A

Chapter 6: Discussion

6.1. Introduction

The previous three chapters present a comprehensive acoustic analysis of the class A and class B consonants. This chapter summarizes the acoustic properties of these consonants. Their distinctive properties are compared with the acoustic properties of other laryngeal contrasts reported in the literature. This survey establishes the uniqueness of the phonetic contrast in Musey. Inferences about the manner in which the contrast in Musey is produced are then considered.

6.2. Summary of the properties of the class A and class B consonants

The class A and class B obstruents are primarily voiceless. The class A [h] and class B [ɦ] are primarily voiced with a tendency for the class A [h] not to exhibit complete voicing. The fricatives and class A [h] and class B [ɦ] also exhibit intermittent voicing.

The two classes exhibit a number of subtle temporal differences. The class A and class B stops and affricates have a small difference in consonant duration with a tendency for the class A stops and affricates to have the longer duration except for the labial stops. The class B fricatives appear to have a longer duration than class A as inferred from the difference in the cumulative duration of the fricative and adjacent vowels. The obstruents also differ in offset voicing time (OFT) with the class B obstruents showing a consistently longer OFT. The class A [h] and class B [ɦ] differ in duration with the class A [h] exhibiting an 18 ms longer duration. The principal temporal properties of these consonants are shown in Table 6.1.

Table 6.1. Comparison of the durational properties of the class A and class B consonants including consonant duration (C), offset voicing time (OFT), duration of voiceless closure (VC), and voice onset time/release duration (VOT).

	C	OFT	VC	VOT
Stops	Longer with class A	7 ms longer with class B	No difference	10 ms longer with class A
Affricates	6 ms longer with class A	5 ms longer with class B	No difference	8 ms longer with class A
Fricatives	Longer with class B	8 ms longer with class B	7 ms longer with class A	NA
h	18 ms longer with class A	NA	NA	NA

In contrast to these small temporal differences, the class A and class B consonants exhibit robust differences in their spectral properties. The class A and class B consonants differ in the amplitude of the burst as well as peak amplitude of frication with the class A consonants produced with greater amplitude as indicated by a greater mean difference in amplitude between consonant and following vowel for the class B consonants. The onset of the vowel [a] exhibits greater spectral tilt and a higher F0 after the class A consonants than after the class B consonants. These spectral properties are summarized in Table 6.2.

Table 6.2. Comparison of the properties of the class A and class B consonants including mean difference in burst amplitude for the stops, affricates, and lateral fricatives (B), mean difference in amplitude of frication for the affricates, fricatives, and h's (FR), spectral tilt as indicated by mean difference of H1-H2 at vowel onset (ST), and mean difference in F0 of [á] at vowel onset (F0).

	B	**FR**	ST	F0
Stops	2.8 dB greater with class B	NA	4.7 dB greater with class A	35 Hz higher with class A
Affricates	1.8 dB greater with class B	4.6 dB greater with class B	3.1 dB greater with class A	48 Hz higher with class A
Fricatives	1.6 dB greater with class B	2.2 dB greater with class B	2.7 dB greater with class A	36 Hz higher with class A
h	NA	1.4 dB greater with class B	0.7 dB greater with class A	37 Hz higher with class A

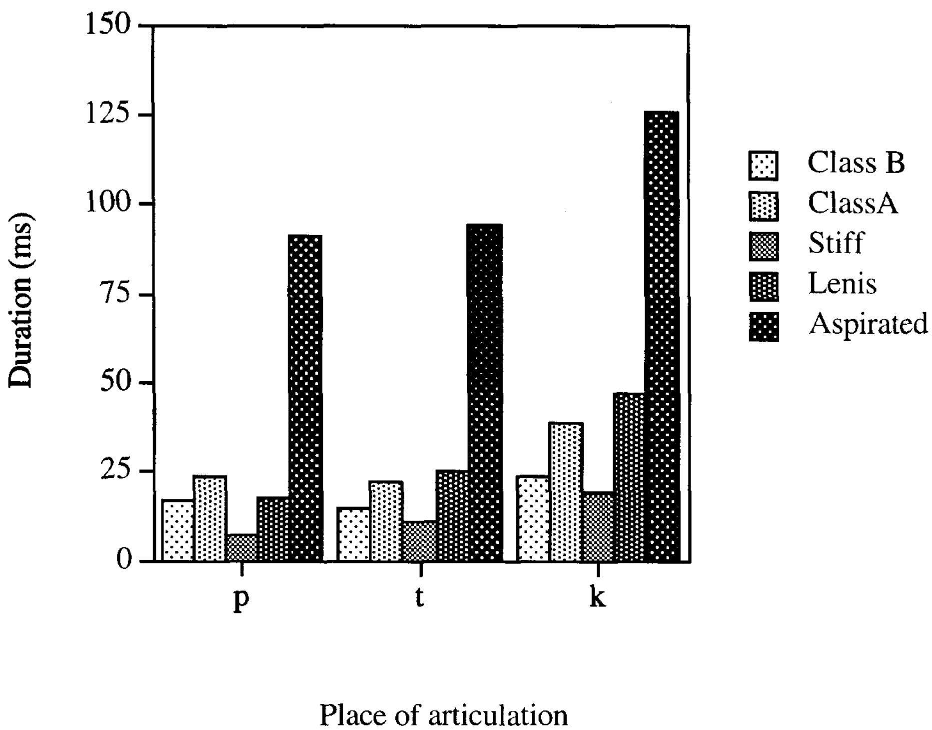
6.3. Comparison with the literature

This section compares the acoustic properties of the class A and class B obstruents with other phonetic categories in the literature involving a contrast between voiceless consonants. First, the class A and class B stop are compared to contrasts in aspiration, e.g. a substantial difference in voice onset time (VOT). Then three contrasts which do not involve a substantial difference in VOT are considered. The acoustic properties of contrasts involving stiff voice and slack voice are examined. Then the class A and class B stops are compared to the "fortis/lenis" contrasts in Zapotec and Jawoñ (Jaeger 1983). These comparisons establish that the contrast in Musey does not represent one of the familiar distinctions reported in the literature.

6.3.1. Aspiration

The most common contrast between voiceless stops involves a difference in aspiration. The difference in VOT between voiceless unaspirated and voiceless aspirated stops ranges from as short as 20 ms to as long as 100 ms (Lisker and Abramson 1964). However, the mean VOT of the class A stops is a mere 10 ms longer than the mean of class B. Figure 6.1. presents the VOT's for the stops of Musey and the stiff, lenis, and aspirated stops of Korean (Lisker and Abramson 1964). Note the small magnitude of the difference in VOT in Musey compared to the difference between the aspirated stops and the other two classes in Korean.

Figure 6.1. Mean VOT for the class A and class B stops of Musey and the stiff, lenis, and aspirated stops of Korean (Lisker and Abramson 1964).



This comparison demonstrates that the class A and class B stops of Musey do not differ in aspiration.

6.3.2. Slack voice

Slack voice has been reported for Javanese (Fagan 1988) and Wu Chinese (Cao and Maddieson 1992) in contrast with voiceless stops. In these languages the contrasting voiceless and slack voice stops are both phonetically voiceless and unaspirated in word-initial position. The voiceless stops are followed by modal voice in the following vowel. Stops with slack voice have a slightly greater glottal aperture and moderate increase in flow in comparison with those followed by modal voice. Consequently, at the onset of the vowel following the slack voice stops there is a lower F0 and greater breathiness than in the vowel following the voiceless stops. In addition, there is known to be larynx lowering associated with the slack voice stops in Javanese (Fagan 1988). In Wu Chinese, the voiceless stops have a longer closure duration than the slack voice stops but the two series of stops do not differ in VOT in word-initial position (Shi 1983; Shen et al. 1987).

In Musey the class A and class B stops show a different distribution of these acoustic properties. The onset F0 of the vowel following the class B stops is lower than the onset F0 after the class A stops which could indicate slack vocal folds. However, unlike the slack voice stops in these languages, the class B stops are not associated with breathiness in the onset of the following vowel. The class B stops have a longer closure duration than the class A stops. Finally, the class A and class B exhibit a small but statistically significant difference in VOT. These differences between the contrast in Musey and the slack voice contrast are summarized in

Table 6.3. with reference to Wu Chinese. Note the similarities between the class A consonants of Musey and the slack voice of Wu Chinese; however, the two differ with respect to their effect on the F0 of the following vowel.

Table 6.3. Comparison of the properties of the class A and class B consonants of Musey with the modal and slack of Wu Chinese (Shen et al. 1987; Cao and Maddieson 1992) including mean stop closure (CL), VOT, spectral tilt (ST), and F0 at vowel onset (F0).

	Musey		Wu Chinese	
	Class A	Class B	Modal	Slack
CL	118 ms	125 ms	155 ms	126 ms
VOT	29 ms	19 ms	17 ms	23 ms
ST	Greater tilt	Lesser tilt	Lesser tilt	Greater tilt
F0	Higher F0	Lower F0	Higher F0	Lower F0

6.3.3 Stiff voice

Stiff voice indicates a degree of vocal fold tension intermediate between modal voice and laryngealization. Korean and Jingpho exhibit contrasts between stiff voice and other categories. Like the contrasts involving modal and slack voice, stiff voice stops are phonetically voiceless and unaspirated in word-initial position. In Korean, the stiff voice or fortis stops contrast with lenis and aspirated stops. The stiff voice stops have a longer closure duration and exhibit a shorter VOT than the lenis stops (Lisker and Abramson 1964; Kagaya 1974; Han 1992, Kim 1994). The onset F0 of the vowel following the stiff voice stops is higher than the onset F0 of the vowel following the lenis stop (Han and Weitzman 1970; Hardcastle 1973; Lee and Smith 1972; Kagaya 1974). In a fiberscopic study Kagaya (1974) determined that the stiff voice stops are produced with a glottal adduction gesture which results in the vocal folds coming together before the release. The lenis stops, on the other hand, exhibit a more constant though partial adduction of the vocal folds during the closure with the glottis still open at the point of release. The stiff voice stops are characterized by higher oral pressure and lower oral flow than the lenis stops (Kim 1965; Hardcastle 1973; Dart 1987). Dart proposed that in addition to the increased tension of the vocal folds, the stiff voice stops are produced with tenser vocal tract walls and greater respiratory muscle force, based on modeling.

The class A stops in Musey are not comparable to the stiff voice stops of Korean. First, they differ with respect to their durational properties. The class A have a shorter closure duration than the class B stops, but the stiff voice stops of Korean have a significantly greater duration than the lenis stops. Moreover, the class A have a longer VOT than the class B stops, but the stiff voice stops of Korean have a shorter VOT than the lenis stops. The Korean stiff voice and Musey class A stops are similar with respect to F0. The vowel following the class A stops has a higher onset F0 than the vowel following the class B stops; in a similar manner, the vowel following the stiff voice stops has a higher onset F0 than the vowel following the lenis stops. However, the amplitude of the burst for the class A stops and the spectral properties of the following vowel suggest that the class A stops are produced with a greater glottal aperture than the class B stops. The Korean stiff voice stops, in contrast, are produced with a closed glottis at release.

Just as the class A stops in Musey differ from the Korean stiff voice stops, the class B stops are also not comparable to the stiff voice stops in Korean. The stiff voice stops have a longer closure duration than the lenis stops. The class B stops also have a longer closure duration. However, the difference in duration between the class A and class B stops is of a significantly smaller magnitude than the difference in closure duration for the stiff voice and lenis stops in Korean. The class B stops have a shorter VOT than the class A stops; likewise, the stiff voice stops have a shorter VOT than the lenis stops. The relatively short VOT's of these stops is a result of the fact that the vocal folds are more adducted at release for these stops than is the case for the glottis of the corresponding lenis stops. The class B stops and the stiff voice stops differ in laryngeal tension as indicated by the onset F0 of the following vowel. The stiff voice stops have a higher onset F0 than the lenis stops. In Musey, however, the class B stops have a lower onset F0 than the class A stops. These differences between the contrast in Musey and the stiff voice contrast of Korean are summarized in Table 6.4. Note the similarities between the class A consonants of Musey and the lenis of Korean; however, the two differ with respect to VOT as well as their effect on the F0 of the following vowel.

Table 6.4. Comparison of the properties of the class A and class B consonants of Musey with the contrasting stiff and lenis of Korean including mean stop closure (CL) (Kim 1994), VOT (Lisker and Abramson 1964), and F0 at vowel onset (F0) (Kagaya 1974).

	Musey		Korean	
	Class A	Class B	Stiff	Lenis
CL	118 ms	125 ms	127	49
VOT	29 ms	19 ms	12 ms	30 ms
F0	Higher F0	Lower F0	Higher F0	Lower F0

Jingpho contrasts stiff voice or tense stops and lax stops (Maddieson and Ladefoged 1985). The stiff voice and lax stops differ in VOT with the lax stops exhibiting a slightly longer VOT. The onset of the vowel following the stiff voice stops has a higher F0. The vowel following the stiff voice stops has a H1-H2 value of -4.0 dB indicating constricted vocal folds. The vowel following the lax stop, however, has a H1-H2 value of 3.6 dB indicating more modal phonation.

The class A and class B stops differ from the stiff voice and lax stops of Jingpho in glottal configuration. The stiff voice stops of Jingpho are more constricted than either of the two classes of stops in Musey. The stiff voice stops have a shorter VOT than the lax stops, but are associated with a higher F0 in the onset of the following vowel. This combination of properties does not match the class A or the class B stops. The class A stops, for instance, have a longer VOT than the class B stops and are also associated with a higher F0 in the onset of the following vowel. These differences between the contrast in Musey and the stiff voice contrast of Jingpho are summarized in Table 6.5.

Table 6.5. Comparison of the properties of the class A and class B consonants of Musey with the stiff and lax of Jingpho (Maddieson and Ladefoged 1985) including mean VOT, mean H1-H2 at vowel onset (ST), and mean F0 at vowel onset (F0).

	Musey		Jingpho	
	Class A	Class B	Stiff	Lax
VOT	29 ms	19 ms	15 ms	35 ms
ST	1.9 dB	-2.4 dB	-4.0 dB	3.6 dB
F0	Higher F0	Lower F0	Higher F0	Lower F0

6.3.4. Fortis/lenis

Like the contrasts involving slack and stiff voice, the contrasting series of fortis and lenis stops in Zapotec and Jawoñ are voiceless, unaspirated in word-initial position (Jaeger 1983). The fortis stops have significantly longer durations. In Zapotec the fortis stops are 102 ms longer than the lenis stops. The fortis stops in Jawoñ are 85 ms longer than the lenis stops. The class A and class B stops, however, do not differ substantially in duration. The class A stops have a greater burst amplitude as indicated by the lower difference of vowel-burst. The fortis stops of Zapotec also exhibit a greater burst amplitude. The class A [s] has a greater amplitude of frication than the class B [z]. The fortis sibilant of Zapotec also has a greater amplitude of frication than the lenis sibilant. Finally, there is greater variation in voicing in Zapotec and Jawoñ with a significant percentage of the lenis stops occurring with partial as well as complete voicing and occurring as fricatives. The fortis stops are consistently voiceless and produced with complete closure. Thus, the class A consonants and the fortis consonants are similar with regard to amplitude and voicelessness. However, the class B consonants and the lenis consonants differ with regard to their duration; moreover, the class B stops are not realized as fricatives as reported for the lenis stops. These differences between the contrast in Musey and the fortis/lenis contrast are summarized in Table 6.6. with specific reference to Zapotec.

6.3.5. Summary

The contrast in Musey between the class A and class B consonants does not represent one of the distinctions reported in the literature. The acoustic properties of the class A and class B obstruents distinguish the contrast in Musey from other contrasts between voiceless consonants in the literature in two respects. First, although the class A and class B consonants have small but statistically reliable differences in duration, the very small magnitude of these temporal differences distinguish the contrast in Musey from each of the contrasts examined in this section. Second, the class A consonants are associated with greater spectral tilt as well as a higher onset F0 in the following vowel. This combination of spectral properties with the class A consonants distinguishes the contrast in Musey from the stiff voice and slack voice contrasts.

Table 6.6. Comparison of the properties of the class A and class B consonants of Musey with the fortis and lenis consonants of Zapotec (Jaeger 1983) including mean consonant duration for the stops (D), mean vowel-burst for stops of Musey (V-B) and amplitude of burst for Zapotec (B), mean vowel-frication for sibilants of Musey (V-F) and amplitude of frication for sibilants of Zapotec (F), and percentage of tokens of stop consonants which are realized as voiceless stops (vless), partially voiced stops (partial), voiced stops, and as fricatives (C).

		Musey		Zapotec	
		Class A	Class B	Fortis	Lenis
D		146 ms	144 ms	163 ms	61 ms
V-B		12 dB	15 dB	-	-
B		-	-	4 dB	2 dB
V-F		21 dB	23 dB	-	-
F		-	-	10 dB	5 dB
C	vless	93%	64%	100%	48%
	partial	7%	35%	0%	5%
	voiced	0%	1%	0%	9%
	fricative	0%	0%	0%	38%

6.4. Inferences about the production of the contrast

The acoustic characteristics of the class A and class B consonants in Musey indicate that this contrast does not represent one of the familiar distinctions reported in the literature. In this section two differences in production between the classes are inferred from their acoustic properties. First, the class A consonants are produced with greater longitudinal vocal fold tension. Second, the class A consonants are produced with an increase in subglottal pressure. Prior to discussing these hypotheses, though, the presence of glottal abduction gestures is considered. It is proposed that both classes are produced with active glottal abduction gestures. However, these abduction gestures do not differ in timing or magnitude and, therefore, do not form the basis of the contrast. These three hypotheses provide a unified account of the acoustic properties of the class A and class B consonants.

6.4.1. Glottal abduction gesture hypotheses

There are several acoustic properties of the class A and class B obstruents which suggest that they are both produced with an active glottal abduction gesture. Moreover, there is reason to believe that these gestures do not differ in timing or magnitude. According to this hypothesis, the small differences in timing between the two classes result from other differences in the production of these classes of consonants. Arguments will be presented against three alternative hypotheses. These are: (a) that the class A obstruents are produced with an active glottal abduction gesture and the class B obstruents are not but are subject to passive devoicing; (b) that the class A obstruents are produced with an active glottal abduction gesture but the class B obstruents are produced with an active adduction gesture; (c) that the class A and class B obstruents are produced with active glottal abduction gestures which differ in timing and magnitude.

The following discussion will focus primarily on the acoustic properties of the class A and class B stops. The inferred differences in production between the two classes of stops are assumed to be the same for the fricatives as well as the class A [h] and class B [ɦ]. The assumption of uniform differences in production across the different manner classes of consonants is supported by the acoustic similarities of the consonants within class A and class B, respectively. For example, across the manner classes the difference in total consonant duration between the class A and class B consonants are small, differing by less than 20 ms. The spectral properties of the vowels following the class A and class B consonants are also comparable across manner classes. Furthermore, it is assumed that a priori it is preferable to adopt a uniform interpretation of the contrast across the different manner classes in the absence of clear empirical evidence to the contrary.

According to the main hypothesis, both the class A and class B obstruents are produced with active glottal abduction gestures which do not differ in timing or magnitude. The principal evidence for an active glottal abduction gesture for these consonants comes from the fact that they are voiceless with relatively short voicing offset time (OFT). In the absence of active supralaryngeal adjustments to facilitate voicing during a stop closure, voicing may persist into the closure for as long as 80 ms (Rothenberg 1968; Ohala 1983; Westbury 1983; Westbury and Keating 1985). An active glottal abduction gesture will hasten the cessation of voicing. For instance, the mean OFT for the voiceless aspirated stops of English and Swedish ranges from 6 to 16 ms (Suomi 1980, Keating 1984, Docherty 1992). In contrast to the aspirated stops, the phonologically voiced stops in these languages are subject to passive devoicing and exhibit mean OFT's ranging from 43 to 84 ms (Suomi 1980, Keating 1984, Docherty 1992). The mean OFT of the class A stops in Musey ranges from 17 to 22 ms; the mean OFT of the class B stops ranges from 20 to 33 ms. The OFT's of the affricates and fricatives are comparable in duration. The relatively short OFT's of both class A and class B obstruents suggest that they are both produced with an active glottal abduction gesture.

An alternate hypothesis would be that the class B obstruents have no abduction gesture and are subject to passive devoicing, but there are supralaryngeal adjustments which inhibit the perseverance of voicing with these consonants. In other words, the class B obstruents would be assumed to devoice passively, but more abruptly than in English, for instance, where active supralaryngeal adjustments may be used to facilitate voicing (Bell-Berti 1975, Westbury 1983). As will be discussed below, there are several acoustic properties of the class A and class B consonants which indicate that the class B consonants are probably produced by some speakers with greater supralaryngeal cavity size and cavity wall compliance. In view of these inferred supralaryngeal adjustments, passive devoicing should produce a substantially longer OFT for the class B obstruents. The short OFT, in spite of these supralaryngeal adjustments which facilitate voicing, argues for the presence of an active abduction gesture with the class B consonants.

An additional alternative would be that the class B obstruents are produced with an active glottal adduction gesture in contrast to an active abduction gesture for class A. Class A stops have a marginally shorter OFT than class B and a slightly longer voice onset time (VOT). In order to produce these differences, it might be that the class B stops are produced with an adduction gesture which inhibits the perseverence of voicing into the stop closure by firmly closing the vocal folds and positions the vocal folds for a more rapid onset of voicing at release. However, there are no signs of laryngealized voicing in the vowels adjoining the class B stops from the waveform and spectrogram displays nor do the spectral tilt measurements for the following vowel indicate laryngealization.

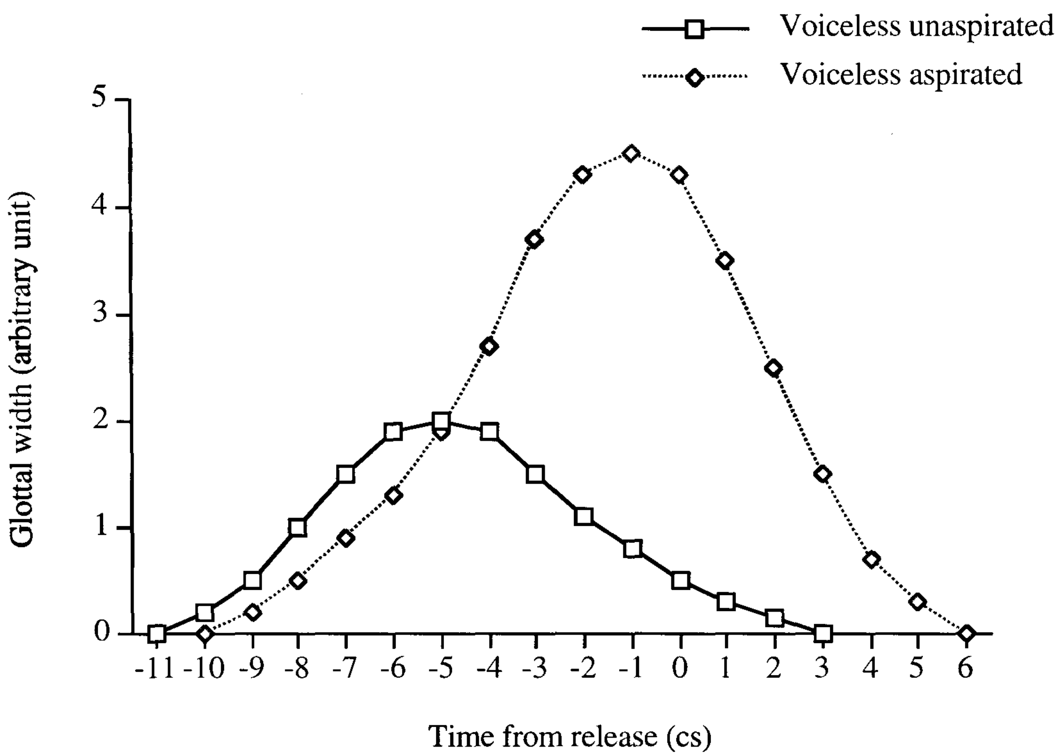
For these reasons, the class A and class B consonants are both assumed to be produced with active glottal abduction gestures. If this is the case, one must then ask how the various measureable differences between them are produced. One possibility is that the class A and class B obstruents are produced with active glottal abduction gestures which differ in timing and/or magnitude. In order to produce the small differences in OFT and VOT, it might be that the class A stops are produced with a slightly more rapid abduction gesture and with a later adduction of the vocal folds. These attributes would likely involve a wider abduction for class A than for class B as aperture appears to co-vary with duration of abduction in most studies of laryngeal gestures (Löfqvist et al. 1981, Lisker and Baer 1984, Löfqvist and Yoshioka 1984, Cooper 1993). However, since the timing difference between class A and class B is very small, only a slight difference between the two classes could be assumed.

These postulated differences in timing and magnitude of abduction gestures are much smaller than are generally seen. The glottal abduction gestures associated with voiceless unaspirated and voiceless aspirated stops such as in Hindi provide a relevant basis of comparison (Dixit 1975, Kagaya and Hirose 1975, Benguerel and Bhatia 1980). This contrast involves large differences in the timing and magnitude of glottal abduction gestures as illustrated in Figure 6.2. The magnitude of the differences in timing and glottal aperture of the glottal abduction gestures associated with these stops are substantially greater than would need to be postulated for Musey.

The within-category variation in VOT for the voiceless unaspirated stops in Hindi is greater than the mean difference in VOT between the two classes of stops in Musey. In the case of the labial stops, for instance, there is a range in VOT from 0 to 25 ms with a mean VOT of 13 ms (Lisker and Abramson 1964). The mean VOT of class A [p] is 24 ms and class B [b] is 17 ms. The fact that the range of variation in VOT in controlled speech for one category in Hindi fluctuates over a much greater range than the mean difference in VOT between the categories in Musey suggests that to create the Musey distinction by different abduction gestures would require more precision in timing and magnitude of glottal abduction gestures than can be reliably achieved in speech.

The presence of intermittent voicing and prevoicing for both classes of fricatives also argues against the hypothesis that class A and class B differ in their glottal abduction gestures. Given the shorter OFT of the class A fricatives, it would be necessary to assume that it was this class which had a more rapid abduction gesture and presumably a wider abduction. However, both classes of fricatives exhibit intermittent voicing and prevoicing. In fact, class A exhibits a significantly greater frequency of intermittent voicing and prevoicing than class B. It must therefore be the case that the vocal folds are relatively close together in the fricatives of this class. Although there are indications that an abduction gesture is present, it must be a relatively small one.

Figure 6.2. Glottal aperture in the abduction gestures for Hindi voiceless aspirated and unaspirated stops (adapted from Benguerel and Bhatia 1980).



Thus, the acoustic properties of the class A and class B consonants indicate that they are produced with active glottal abduction gestures which do not differ in timing or magnitude. It follows that the small temporal differences between the classes discussed in this section are more plausibly attributed to other differences in production. These inferred differences in production and their effect on the temporal properties of these two classes of consonants are considered in the next section.

6.4.2. The longitudinal tension hypothesis

There are several acoustic properties of the class A and class B consonants which suggest that they are produced with differing degrees of longitudinal vocal fold tension. In particular, the class A consonants exhibit acoustic properties which may indicate that the class is produced with greater longitudinal tension resulting from greater contraction of the cricothyroid muscle. The acoustic properties in support of this hypothesis are considered in this section.

6.4.2.1. Longitudinal vocal fold tension and consonant production

The vocal fold consists of the vocalis muscle which comprises the body of the fold and the mucosa epithelium and lamina propria which comprise the cover of the fold (Hirano 1975, Sawashima and Hirose 1983). The longitudinal tension of the vocal folds is determined by the relative stiffness of the body and cover (Hirano 1975). Two intrinsic laryngeal muscles are primarily responsible for longitudinal tension: the cricothyroid and vocalis muscles. Contraction of the cricothyroid muscle rotates the thyroid cartilage relative to the cricoid cartilage and, thereby, lengthens the vocal folds by increasing the distance between their attachments (Hirano 1975, Sonesson 1982). Elongation of the vocal folds increases the stiffness of the body and the cover of the folds. Contraction of the vocalis muscle increases the tension of the vocal folds through stiffening the body of the vocal folds while slackening the cover of the folds due to the resultant shortening (Hirano 1976).

Both intrinsic laryngeal muscles have been shown in electromyographic studies to be involved in the production of consonantal voicing contrasts. Collier et al. (1979), for instance, report that the vocalis muscle has higher levels of activity in voiceless unaspirated stops than in voiced stops in Dutch. These stops differ in the presence/absence of abduction. However, it is assumed here for Musey that significant differences in vocalis activity do not occur between class A and class B because they do not differ in glottal abduction gestures, as argued above.

Studies of cricothyroid activity in the production of voicing contrasts indicate that there is a tendency for increased cricothyroid activity to be associated with voicelessness but that the relationship is not a necessary one. Voiceless aspirated stops exhibit greater cricothyroid activity than voiceless unaspirated stops in Danish (Fischer-Jørgensen and Hirose 1974, Hutters 1985). Based on data from one subject, Dixit (1975) and Dixit and MacNeilage (1980) report that the voiceless aspirated and unaspirated stops of Hindi exhibit a higher level of cricothyroid activity than the voiced stops. Kagaya and Hirose (1975), however, did not find higher levels of activity with the voiceless aspirated and unaspirates stops of Hindi for their subject. Löfqvist et al. (1989) report greater cricothyroid activity in the voiceless aspirated stops of English than in the voiced stops. They also report a similar finding for Dutch based on data from one subject; however, Collier et al. (1979) found no difference with data from another speaker of Dutch. Finally, other studies reveal no relationship between cricothyroid activity and the production of voicing contrasts in English (Hirose and Gay 1972), Korean (Hirose et al. 1974), and Japanese (Hirose and Ushijima 1978).

In the studies which do show a relation between cricothyroid activity and voicelessness, it is significant that the greatest difference in activity is timed with the onset of the consonant. Dixit and MacNeilage (1980) report that cricothyroid activity is significantly higher at the onset of closure for the voiceless unaspirated stop than for the voiceless aspirated stops in Hindi. The level of cricothyroid activity between the two categories is similar at release, though. They propose that cricothyroid activity facilitates devoicing in the voiceless unaspirated stops. Löfqvist et al. (1989) also propose that control of longitudinal vocal fold tension by means of the cricothyroid muscle may be utilized as a devoicing mechanism. In the following section arguments are presented for increased activation of the cricothyroid muscles with the class A consonants.

6.4.2.2. The longitudinal tension hypothesis

Increased longitudinal vocal fold tension resulting from increased cricothyroid activation offers the most plausible explanation for several acoustic properties of the class A and class B consonants, including the F0 and spectral tilt differences in the following vowel as well as temporal differences in consonants. Increased activation of the vocalis muscle could also account for several of the differences between the two classes. The reasons for positing increased cricothyroid but no increase in vocalis activity are considered in the following discussion.

As discussed in Chapter 5, the class A consonants are associated with a higher F0 at the onset of the following vowel than is the case at the onset of the vowel following the class B consonants. Moreover, the F0 remains significantly higher for the remainder of the vowel with class A. There is no reliable effect of consonant class on the F0 of the preceding vowel. Increased longitudinal tension with the class A consonants resulting from greater cricothyroid activity offers a plausible account of these differences in the F0 of the adjacent vowels.

Contraction of the cricothyroid muscle elongates the vocal folds and thereby increases the stiffness of the body and the cover of the folds. Increases in longitudinal tension raise F0 during phonation. Thus, cricothyroid activity is highly correlated with F0 (Katsuki 1950, Faaborg-Andersen 1957, Faaborg-Andersen 1965, Hirano et al. 1969, Hirano 1975, Sonesson 1982). Contraction of the vocalis muscle increases the tension of the vocal folds through stiffening the body of the vocal folds. Vocalis activity is also correlated with F0 (Faaborg-Andersen 1957, Faaborg-Andersen 1965, Hirano et al. 1969, Gay et al. 1972, Atkinson 1978, Shipp et al. 1979, Kempster et al. 1988). Direct stimulation of these muscles also raises the F0 of phonation (Kempster et al. 1988, Titze et al. 1989).

Titze et al. (1989) investigate the relative contribution of the cricothyroid and vocalis muscles to the regulation of F0 in an electromyographic study. According to their theoretical muscle activation plot, raising F0 within the frequency range associated with speech could be accomplished solely with an increase in cricothyroid activity, solely with an increase in vocalis activity, or with a coordinated increase in activity for both muscles. In the case of an increase from 150 to 200 Hz involving maximum coordinated increases in muscle activity, the cricothyroid increases from 20% to 40% activation while the vocalis increases from 10% to 22% activation. In the case of no increase in vocalis activity, an increase from 20% to 55% activation for the cricothyroid could produce the 50 Hz increase. The increase in F0 in Musey could, therefore, involve potentially an increase in either cricothyroid or vocalis muscle activation or both. However, the contribution of the vocalis muscle must be negligible. A substantial increase in the level of vocalis activity would facilitate voicing by decreasing the glottal aperture and, thereby, produce a longer OFT and shorter VOT for the class A consonants. Thus, the inferred differences in longitudinal tension are attributed primarily to the cricothyroid muscle.

The absence of an effect of the class A consonants on the F0 of the preceding vowel but the robust effect on the F0 of the following vowel requires an explanation consistent with the physiological characteristics of the cricothyroid muscle. The cricothyroid muscle has a response latency of 11-40 ms (Atkinson 1978, Sapir et al. 1982, Kempster et al. 1988). It is, therefore, necessary to posit that the cricothyroid muscle is not activated any earlier than 40 ms before the acoustic onset of the consonant, since no effect on the preceding F0 is observed.

The perseverance of the effect of the class A consonants on the F0 of the following vowel may be attributed to the response time of the cricothyroid muscle. The duration of the response of the cricothyroid muscle to stimulation ranges from 60 to 100 ms (Kempster et al. 1988). Dixit and MacNeilage (1980) report the highest levels of cricothyroid activity for the voiceless unaspirated and voiceless aspirated stops at the middle of stop closure. If it were assumed that the higher level of cricothyroid stimulation posited for class A stops ceased at the middle of the stop closure, then, since the average stop duration is 147 ms, the muscle might continue to exhibit greater tension resulting from its slow contraction and relaxation time for as long as 30 ms into the following vowel. This is inadequate to account for the observed pattern in Musey. Given that the mean duration of [a] is 81 ms as seen in Table 4.7., the effect of increased longitudinal tension would persist for only the first third of the vowel at most under this assumption. It is, therefore, necessary to posit that the higher level of stimulation continues until within 20 ms of the offset of the class A consonant or later.

An additional difference between the vowels after the class A and class B consonants which may also suggest that there are differences in longitudinal tension is spectral tilt. Since the vowels following the class A consonants have a greater spectral tilt, a greater open quotient can be inferred in each glottal pulse. Increased cricothyroid activity results in a greater open quotient as shown during sustained phonation in the in vivo canine model (Yumoto et al. 1995). The differences in spectral tilt are consistent with the different levels of cricothyroid activity posited to account for F0 patterns. The absence of the spectral tilt difference in the vowel preceding the class A and class B consonants as well as the perseverance of the difference in the vowel following these consonants are also consistent with positing that the highest level of cricothyroid activity occurs at or near the onset of the consonant. An increase in vocalis activity, on the other hand, decreases the open quotient in phonation (Kempster et al. 1983); thus, a substantial difference in vocalis activity would decrease the open quotient in the vowel following the class A consonants. For these reasons, the inferred differences in longitudinal tension are attributed to the cricothyroid muscle.

Recall that the class A obstruents have a slightly shorter offset voicing time (OFT) than the class B obstruents. In section 6.4.1. it was argued that differences in duration of such a small magnitude were unlikely to arise from actively controlled timing differences. The longitudinal tension hypothesis could account for these small durational differences as an indirect consequence of differences in tension. Greater longitudinal vocal fold tension inhibits the ability of the vocal folds to oscillate in low volume velocity flows (Halle and Stevens 1971, Westbury 1983). Thus, greater cricothyroid activity at the onset of the consonant could facilitate the cessation of voicing in the class A obstruents, resulting in shorter OFT.

In addition, the increased longitudinal tension could impede the onset of voicing at the release of class A obstruents. Contraction of the cricothyroid muscle also produces a small degree of vocal fold abduction (Sawashima and Hirose 1983). A small difference in glottal aperture in combination with greater longitudinal vocal fold tension at release could produce the longer VOT of the class A stops.

If greater cricothyroid activity contributes to shorter VOT and if cricothyroid activity controls the F0 of the tone of the following vowel, then the VOT of each class might be shorter when the follow vowel has a high tone compared to a mid tone. In order to test for an effect of tone on VOT for the class A and class B stops, a three-factor analysis of variance was conducted with the variables consonant class, tone, and place of articulation. The tone of the following vowel has a significant effect on the VOT of the preceding stop ($F[1,775]=8.24$, $p<.0042$). However, the direction of the effect is opposite of what is anticipated. The mean VOT of the stops preceding the mid tone [ā] was 2 ms longer than the mean VOT of the stops preceding the high tone [á]. However, the consonant class of the preceding consonant is a much stronger predictor of the onset F0 of a vowel than the tone of the vowel as seen in Figures 5.7. and 5.8. The absence of the expected effect is attributable to the fact that any difference in cricothyroid activity resulting from the tone of the vowel at its onset is small compared to the effect of the inherent cricothyroid activity of the consonant at this point.

6.4.3. The subglottal pressure hypothesis

The class A consonants have greater amplitude than the class B consonants. The differences in the amplitude of the class A and class B consonants cannot be adequately explained solely in terms of the proposed increase in longitudinal vocal fold tension and glottal abduction gestures. The presence of intermittent voicing and its greater frequency with the class A fricatives also remain unexplained. A difference in subglottal pressure is proposed to account for these properties.

The burst amplitude of the class A stops and affricates is greater than it is for the class B stops and affricates. The amplitude of a burst is determined among other things by the intraoral air pressure at the time of release of the closure. Thus, the relative differences in burst amplitude provide a basis for inferring differences in intraoral air pressure provided other potential differences in production can be assumed to be negligible. Stevens (1971) demonstrates that in the production of turbulent noise, the radiated sound pressure of the noise is approximately proportional to the 1.5 power of the pressure drop across the constriction assuming a given constriction size. Zue (1980) reports a difference in relative burst amplitude of 2 dB between the voiced and voiceless alveolar stops of English. He notes that these differences in amplitude indicate an approximate intraoral air pressure ratio of voiceless with respect to voiced stops of 1.35 which is consistent with results in the literature (Subtelney et al. 1966, Malécot 1968, Lisker 1970). For Musey, the burst amplitude of the class A and class B labial stops differ by 4.3 dB which indicates an approximate intraoral air pressure ratio of 1.93. Based on the intraoral air pressure values reported in the literature for voiced labial stops in English (Subtelney et al. 1966, Malécot 1968), it is plausible that the class B labial stop has an approximate intraoral air pressure within the range of 2.5 to 4.5 cm/H_20 since the vocal folds are not widely abducted in the class B stops. Assuming this range of intraoral air pressures for the class B labials, the intraoral air pressure of the corresponding class A labial stops would be from 4.8 to 8.7 cm/H_20 according to the approximate ratio of 1.93. Thus, the approximate magnitude of the difference would be within the range of 2.3 to 4.2 cm/H_20.

The maximum intraoral air pressure during a voiceless stop closure is equal to the subglottal pressure if the vocal folds are not adducted (Ladefoged 1967, 1968; Netsell 1969, Scully 1969, Shipp 1973, Dixit and Brown 1976, Löfqvist and Pétursson 1978). Both classes of stops and affricates in Musey are produced with a similar degree of vocal fold abduction and comparable closure durations. Thus, the intraoral air pressure might be expected to be equal between the two classes and probably equal to the subglottal pressure in both cases, given their closure durations. Nonetheless, differences in intraoral air pressure are inferred for these consonants. One possibility might be that there are differences in supralaryngeal cavity size and vocal tract wall compliance between the two classes. If such differences are of sufficient magnitude, and if the degree of vocal fold adduction was enough to maintain separate pressures above and below the glottis, it might be conceivable that the oral pressure in one class (class B) could be prevented from reaching equality with subglottal pressure. Another possibility would be that the class A consonants are produced with greater subglottal pressure.

In their aerodynamic modelling study of intraoral air pressure, Müller and Brown (1980) quantify the relative contributions of glottal aperture, wall compliance, supralaryngeal cavity size, and subglottal pressure to intraoral air pressure in labial stops. They propose that a difference in supralaryngeal wall compliance between moderate and lax compliance results in a difference in intraoral air pressure of approximately 0.9 cm/H_20. Furthermore, active expansion of supralaryngeal cavity size in conjunction with lax wall compliance results in an additional difference in intraoral air pressure of approximately 0.9-1.5 cm/H_2O. Thus, if the vocal folds are sufficiently adducted to maintain a pressure difference and if the class B labial stops were produced with lax wall compliance and supralaryngeal cavity expansion, the intraoral air pressure at release would be approximately 1.8-2.6 cm/H_2O lower than for the class A labial stop produced with moderate wall compliance and no cavity expansion.

However, the frequency of F1 indicates that the class B [d] is produced with cavity expansion for only one of the speakers. In fact, for three speakers greater cavity size is inferred in the production of the class A [t] and the remaining four show no evidence of a difference. These relative differences in cavity size are assumed to hold of the stops at the other places of articulation for these speakers.

If supralaryngeal cavity size contributes significantly to the differences in intraoral air pressure in Musey, then the three separate patterns of cavity size observed in these speakers should contribute to the inferred differences in the intraoral air pressure. In other words, speakers with greater cavity size for class B [d] might be expected to have relatively lower burst amplitudes for [d] than speakers with no difference in cavity size between class A [t] and class B [d]. The difference of vowel-burst for class A [t] and class B [d] was submitted to a two factor analysis of variance with the factors consonant class and cavity size (class A [t] larger than class B [d], class A [t] smaller than class B [d], or no difference). The inferred differences in cavity size do not have a significant effect on the vowel-burst difference ($F[2,291]=1.65$, $p<.1931$). Moreover, a post-hoc comparison of means indicates that the vowel-burst differences for the speaker who produces class B [d] with greater cavity size are not significantly different from those of the speakers with no difference in cavity size or greater cavity size with class A [t]. The absence of a significant effect indicates that the inferred differences in supralaryngeal cavity size do not contribute significantly if at all to the differences in intraoral air pressure between the two classes of stops as inferred from burst amplitude.

Regarding wall compliance, greater wall compliance with the class B stops and affricates could contribute to a lower intraoral air pressure. However, only four speakers exhibit greater wall compliance with the class B [d] as inferred from the bandwidth of F4. In order to determine if wall compliance contributes significantly to the differences in intraoral air pressure in Musey, the difference of vowel-burst for class A [t] and class B [d] was submitted to a two factor analysis of variance with the factors consonant class and bandwidth of F4 (class B [d] greater than class A [t] or no difference). The differences in bandwidth of F4 have a significant effect on the difference of vowel-burst ($F[1,293]=30.44$, $p<.0001$). However, the direction of the effect is not the expected one: the stops with greater bandwidth of F4 exhibit greater amplitude. Thus, the differences in wall compliance inferred from the differences in the bandwidth of F4 cannot account for the differences in intraoral air pressure. In fact, it appears that in the case of the speakers who are inferred to have a difference in wall compliance, some additional difference in the production of these consonants compensates for the potential reduction in intraoral air pressure due to greater wall compliance.

The inferred differences in supralaryngeal cavity size and wall compliance cannot account for the differences in intraoral air pressure between the two classes of stops as inferred from burst amplitude. This suggests that some other factor is consistently employed in the production of these consonants and is responsible for the differences in intraoral air pressure. It is, therefore, proposed that the class A consonants are produced with an increase in subglottal pressure compared to class B. It is this difference in subglottal pressure which accounts for the burst amplitude differences.

The greater amplitude of the affrication of the class A affricates and of the frication of the class A fricatives is also consistent with a difference in subglottal pressure. Greater subglottal pressure with the class A affricates and fricatives would produce greater airflow and, consequently, greater amplitude of frication. Because fricatives are produced with an incomplete supralaryngeal constriction, the level of intraoral air pressure cannot reach the level of subglottal pressure during the interval of frication. Thus, a transglottal pressure differential exists during the frication. An increase in subglottal pressure would increase the transglottal pressure differential and facilitate voicing during the fricatives. The proposal of greater subglottal pressure with class A thereby accounts for the greater frequency of intermittent voicing as well as prevoicing for the class A fricatives.

The effect of the class A consonants on the F0 and spectral tilt of the following vowel was attributed to increased longitudinal vocal fold tension in the preceding section. An increase in subglottal pressure produces a rise in the F0 of phonation (Ladefoged 1963, Öhman and Lindqvist 1966, Baer 1979, Strik and Boves 1989). The observed F0 effect cannot be attributed to subglottal pressure differences alone since the magnitude of the F0 difference is too large. However, the subglottal pressure difference would add to the F0 effect. In a similar manner, the difference in subglottal pressure may also contribute to the greater spectral tilt observed in the vowel following the class A consonants. Titze et al. (1989) report that the open quotient increases with F0 of phonation as well as the amplitude.

It has been argued that the proposed difference in subglottal pressure provides an explanation for several of the acoustic characteristics of the class A and class B consonants. However, if the class A obstruents are produced with greater subglottal pressure, it might be expected that they would exhibit longer offset voicing time (OFT). This is because increasing subglottal pressure will maintain a sufficient transglottal pressure differential to sustain voicing for a longer interval following closure. Consider data on English reported by Keating (1984) comparing stressed and unstressed environments. The OFT of voiceless stops preceding a vowel with primary stress is from 3 to 10 ms longer than the OFT of these stops preceding a reduced vowel. Since stress in English is produced by higher subglottal pressure, effects of this magnitude might be expected with the class A stops of Musey. However, the increased longitudinal vocal fold tension indicated by the higher F0 after class A stops could impede a longer OFT for the class A stops despite the greater subglottal pressure.

The increased subglottal pressure hypothesis predicts that the vowel following the class A consonants might have a greater amplitude at its onset. Measurements of the amplitude of the vowel at its onset were not made. However, the peak amplitude in the middle of the vowel [a] is significantly greater after the class B stops and affricates than after the class A stops and affricates. This difference is only 1.0 dB, though, and there is no difference in the peak amplitude of the vowel [a] after the class A and class B fricatives or after class A [h] and class B [ɦ]. These findings indicate that there is essentially no difference in the peak amplitude of the vowel following either class. It could be the case, nonetheless, that the proposed differences in subglottal pressure affect the amplitude of the following vowel. A difference in amplitude at the onset of the vowel which is not as great as the peak amplitude of the vowel would not be detected with the peak amplitude measurement. If there is, in fact, a difference in amplitude at the onset of the vowel, it must not be a large difference or persist significantly into the vowel; otherwise it would affect the peak amplitude measurement.

To account for the acoustic properties of the class A and class B consonants outlined in this section, it is necessary to posit an increase in subglottal pressure with the class A consonants. The effect of the subglottal pressure increase on the amplitude of these consonants but not the adjacent vowels indicates that the pressure increase is timed to coincide with the consonant. Thus, it is assumed that the increase in subglottal pressure is approximately 125 ms in duration and is timed to occur during the consonant. An increase in subglottal pressure of this duration is consistent with the duration of increases in subglottal pressure reported for emphatically stressed syllables (Ladefoged 1963, 1967, 1968; Lieberman 1967, Leanderson et al. 1987, Sundberg et al. 1993).

The latency of the respiratory system may range from 120-320 ms (Ladefoged 1962, 1967, 1968; Baken et al. 1979; Shipp et al. 1984). Given the slow latency of the system, it is assumed that the initiation of the subglottal pressure increase is timed prior to the consonant in order to produce a peak subglottal pressure during the consonant. In order to account for the greater amplitude of the stops and affricates, the peak subglottal pressure is assumed to occur immediately prior to the release of the oral closure for the stops and affricates. The difference in pressure would rapidly decline during the interval of VOT and the first approximately 20 ms of the following vowel. The increased pressure at release would facilitate the higher F0 at the onset of the vowel but not affect the peak amplitude of the vowel.

Thus, the observed acoustic differences between the two classes of consonants in Musey can be accounted for quite well by the hypotheses that the class A consonants are produced with greater longitudinal vocal fold tension as well as greater subglottal pressure.

6.5. Conclusion

This dissertation has documented the existence of a previously unknown laryngeal contrast. Despite the subtle nature of this phonetic contrast, it is has a prominent role in the phonetics and phonology of the Musey language, especially in relation to the tone pattern of a word. The acoustic properties of the contrasting consonants indicate that they differ primarily in longitudinal vocal fold tension with the class A consonants exhibiting greater tension. There is also strong motivation for positing greater subglottal pressure for the class A consonants. Both classes of consonants are produced with glottal abduction gestures. However, there is no evidence from the acoustic properties of these consonants indicating that the two classes differ in the timing or magnitude of their glottal abduction gestures. This contrast reveals the inadequacy of previous classifications of laryngeal contrasts based solely on differences in the timing and magnitude of glottal abduction and adduction gestures. This laryngeal contrast in Musey underscores the fact that there is greater diversity in the laryngeal and pulmonary mechanism utilized in speech than previously realized.

Appendix

The following tables contain the numerical data reported in the dissertation for the stop consonants. The data reported for the affricates, fricatives, and h's can be found in the version of this dissertation available through University Microfilms International. In each of the following tables, the token is identified by the initial consonant and the tone of the word; 'h' designates a high toned word, 'm' a mid toned word. The number of the token precedes the period. The number following the period designates the speaker; speaker JO is identified by '1', AV '2', AK '3', EL '4', PA '5', EF '6', BE '7', and TA '8'. Thus, 'ph2.1' designates the second token of [pát] of the first speaker, JO.

Table 7.1. Numerical data for the duration (seconds) of the preceding vowel [i], offset voicing time (OFT), voiceless closure duration (VLC), voice onset time (VOT), and duration of the vowel [a] for the class A and B stops.

[i]	OFT	VLC	VOT	[a]	
.0697	.0148	.1062	.0174	.0904	ph1.1
.0586	.0097	.1035	.0177	.0901	ph2.1
.0457	.0099	.0997	.0166	.0772	ph3.1
.0364	.0103	.1104	.0170	.0818	ph4.1
.0608	.0104	.1044	.0176	.0723	ph5.1
.0365	.0104	.1085	.0178	.0831	ph6.1
.0616	.0142	.1164	.0171	.0773	ph7.1
.0499	.0099	.1196	.0170	.0795	ph8.1
.0450	.0033	.1267	.0168	.0780	ph9.1
.0392	.0110	.1169	.0176	.0714	pm1.1
.0439	.0111	.1255	.0177	.0741	pm10.1
.0553	.0121	.1213	.0181	.0768	pm11.1
.0642	.0109	.1205	.0197	.0797	pm12.1
.0320	.0100	.1304	.0269	.0715	pm2.1
.0344	.0149	.1187	.0187	.0703	pm3.1
.0468	.0114	.1035	.0273	.0715	pm4.1
.0518	.0131	.1164	.0275	.0790	pm5.1
.0562	.0115	.1091	.0198	.0758	pm6.1
.0635	.0142	.1165	.0199	.0857	pm7.1
.0462	.0115	.1160	.0188	.0801	pm8.1
.0498	.0131	.1168	.0179	.0809	pm9.1
.0589	.0116	.1288	.0144	.0984	bh1.1
.0413	.0261	.1348	.0216	.0927	bh2.1
.0780	.0143	.1327	.0157	.0953	bh3.1
.0931	.0120	.1119	.0168	.0803	bh4.1
.0604	.0152	.1348	.0161	.0764	bh5.1
.0645	.0103	.1330	.0156	.0843	bh6.1
.0604	.0102	.1266	.0155	.0821	bh7.1
.0662	.0114	.1297	.0097	.0892	bh8.1
.0523	.0162	.1446	.0139	.0813	bh9.1
.0746	.0139	.1115	.0152	.0810	bm1.1
.0631	.0212	.1233	.0169	.0825	bm2.1
.0805	.0175	.1319	.0146	.0813	bm3.1
.0537	.0113	.1241	.0188	.0739	bm4.1
.0764	.0095	.1125	.0167	.0831	bm5.1
.0627	.0164	.1091	.0166	.0742	bm6.1
.0584	.0213	.1120	.0198	.0642	bm7.1
.0509	.0161	.1194	.0160	.0658	bm8.1
.0685	.0162	.1103	.0163	.0658	bm9.1
.0595	.0205	.1087	.0259	.0704	th1.1
.0580	.0127	.1242	.0198	.0727	th2.1
.0591	.0218	.0962	.0185	.0666	th3.1
.0615	.0126	.1182	.0169	.0698	th4.1
.0622	.0170	.1129	.0226	.0771	th5.1
.0425	.0135	.1111	.0192	.0701	th6.1
.0747	.0137	.0966	.0272	.0673	th7.1
.0732	.0195	.1001	.0239	.0575	th8.1
.0617	.0190	.0944	.0246	.0674	th9.1
.0496	.0144	.0959	.0216	.0692	tm1.1
.0684	.0139	.1194	.0222	.0777	tm2.1
.0627	.0212	.1011	.0303	.0557	tm3.1
.0427	.0215	.0936	.0218	.0593	tm4.1
.0488	.0236	.1103	.0287	.0527	tm5.1
.0586	.0175	.1072	.0294	.0565	tm6.1
.0505	.0166	.1079	.0519	.0397	tm7.1
.0530	.0158	.1304	.0229	.0613	tm8.1
.0664	.0253	.0931	.0138	.0672	tm9.1
.0702	.0231	.1203	.0158	.0853	dh1.1
.0611	.0209	.1249	.0179	.0853	dh2.1
.0886	.0120	.1234	.0113	.0815	dh3.1
.0742	.0229	.0955	.0193	.0514	dh4.1
.0957	.0170	.1042	.0196	.0619	dh5.1
.0603	.0152	.1320	.0187	.0711	dh6.1
.0711	.0140	.1269	.0192	.0752	dh7.1
.0834	.0206	.1015	.0198	.0682	dh8.1
.0805	.0143	.1063	.0181	.0684	dh9.1
.0613	.0204	.0972	.0174	.0646	dm1.1

.0807	.0204	.0970	.0158	.0737	dm2.1
.0703	.0196	.1126	.0165	.0795	dm3.1
.0514	.0200	.0919	.0168	.0636	dm4.1
.0750	.0143	.1222	.0190	.0652	dm5.1
.0591	.0275	.0921	.0168	.0678	dm6.1
.0557	.0211	.0776	.0556	.0622	kh1.1
.0674	.0207	.0952	.0420	.0701	kh2.1
.0597	.0204	.1028	.0475	.0463	kh3.1
.0708	.0138	.0946	.0360	.0711	kh4.1
.0550	.0203	.0948	.0459	.0561	kh5.1
.0339	.0167	.0985	.0356	.0627	kh6.1
.0391	.0199	.0888	.0380	.0636	kh7.1
.0560	.0192	.0946	.0348	.0633	kh8.1
.0468	.0194	.0994	.0329	.0660	kh9.1
.0645	.0205	.0878	.0439	.0592	km1.1
.0597	.0202	.1057	.0440	.0685	km2.1
.0755	.0202	.1043	.0384	.0609	km3.1
.0434	.0199	.0913	.0425	.0498	km4.1
.0781	.0210	.0780	.0408	.0509	km5.1
.0991	.0205	.1023	.0395	.0528	km6.1
.0556	.0138	.0817	.0386	.0444	km7.1
.0700	.0128	.0873	.0399	.0569	km8.1
.0582	.0163	.0894	.0424	.0446	km9.1
.0694	.0131	.1208	.0256	.0737	gh1.1
.0707	.0187	.1120	.0209	.0771	gh2.1
.0725	.0205	.1214	.0266	.0743	gh3.1
.0279	.0143	.1213	.0257	.0723	gh4.1
.0490	.0139	.0901	.0251	.0748	gh5.1
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.0690	.0194	.1173	.0398	.0715	gh9.1
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.0690	.0428	.1267	.0190	.1212	bm9.2
.0918	.0112	.0895	.0164	.1002	th1.2
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.0718	.0193	.1104	.0170	.1114	th3.2
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.0204	.0233	.0713	.0507	.0371	kh9.3
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.0535	.0240	.1127	.0407	.0796	kh5.4
.0441	.0202	.1149	.0411	.0746	kh6.4
.0404	.0192	.1130	.0360	.0729	kh7.4
.0510	.0183	.1124	.0395	.0777	kh8.4
.0512	.0195	.0992	.0377	.0695	kh9.4
.0372	.0185	.1050	.0402	.0784	km1.4
.0443	.0139	.1142	.0349	.0788	km2.4
.0381	.0135	.1147	.0314	.0846	km3.4
.0509	.0191	.1025	.0369	.0754	km5.4
.0285	.0121	.1206	.0439	.0667	km6.4
.0403	.0097	.1196	.0400	.0798	km7.4
.0503	.0182	.1089	.0408	.0870	km8.4
.0554	.0238	.1082	.0384	.0874	km9.4
.0440	.0149	.1204	.0251	.0856	gh1.4
.0391	.0122	.1142	.0267	.0789	gh10.4
.0400	.0178	.1173	.0244	.0944	gh11.4
.0462	.0184	.1129	.0285	.0891	gh12.4
.0242	.0107	.1388	.0223	.0780	gh2.4
.0299	.0149	.1403	.0226	.0826	gh3.4
.0301	.0126	.1196	.0215	.0932	gh4.4
.0426	.0157	.1171	.0243	.0855	gh5.4

.0239	.0144	.1247	.0303	.0831	gh6.4
.0576	.0136	.1160	.0220	.0845	gh7.4
.0602	.0119	.1300	.0270	.0749	gh8.4
.0580	.0188	.1154	.0304	.0832	gh9.4
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.1275	.0235	.1050	.0210	.1075	ph1.5
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.0719	.0204	.1041	.0334	.0912	pm2.5
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.1082	.0350	.1169	.0162	.1201	bh2.5
.0785	.0171	.1211	.0150	.1036	bh3.5
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.0976	.0245	.0984	.0233	.1176	bh6.5
.1059	.0341	.0652	.0435	.1115	bh7.5
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.0906	.0223	.1049	.0151	.1138	bh9.5
.1145	.0200	.1074	.0449	.1162	bm1.5
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.1419	.0135	.1280	.0534	.1121	bm9.5
.1291	.0288	.1032	.0220	.0852	th1.5
.1380	.0229	.1172	.0182	.0971	th2.5
.1142	.0121	.1159	.0225	.0822	th3.5

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.1029	.0181	.1244	.0172	.0886	th7.5
.1420	.0244	.1063	.0204	.0984	th8.5
.1392	.0187	.1031	.0257	.0976	th9.5
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.1370	.0129	.1091	.0399	.0962	tm2.5
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.1139	.0278	.0743	.0380	.0776	kh3.5
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.0538	.0143	.0815	.0291	.0664	km12
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.0366	.0377	.0912	.0226	.1163	ph6.8
.0482	.0347	.0799	.0277	.1156	ph7.8
.0227	.0418	.0781	.0320	.1266	ph8.8
.0431	.0287	.0838	.0270	.1238	ph9.8
.0382	.0290	.0999	.0308	.1066	pm1.8
.0285	.0428	.0771	.0318	.1133	pm2.8
.0367	.0318	.0803	.0402	.1000	pm3.8
.0437	.0223	.1000	.0301	.1022	pm4.8
.0434	.0291	.0815	.0293	.1099	pm5.8
.0307	.0284	.1050	.0292	.1136	pm6.8
.0364	.0405	.0696	.0373	.1132	pm7.8
.0414	.0286	.0802	.0220	.1276	pm8.8
.0236	.0340	.0758	.0207	.1230	pm9.8
.0507	.0304	.0835	.0132	.1340	bh1.8
.0446	.0306	.0828	.0125	.1236	bh2.8
.0310	.0347	.0843	.0106	.1250	bh3.8
.0358	.0373	.0927	.0115	.1177	bh4.8
.0419	.0384	.0790	.0111	.1386	bh5.8
.0170	.0352	.0791	.0113	.1112	bh6.8
.0222	.0439	.0823	.0132	.1368	bh7.8
.0299	.0328	.0993	.0143	.1336	bh8.8
.0232	.0390	.0799	.0113	.1188	bh9.8
.0266	.0429	.0755	.0180	.1214	bm1.8
.0345	.0494	.0689	.0110	.1486	bm2.8
.0286	.0435	.0847	.0112	.1300	bm3.8
.0232	.0496	.0830	.0117	.1342	bm4.8
.0240	.0556	.0741	.0102	.1357	bm5.8
.0316	.0430	.0748	.0109	.1231	bm6.8
.0306	.0510	.0750	.0121	.1287	bm7.8
.0367	.0430	.0706	.0125	.1254	bm8.8
.0311	.0442	.0671	.0126	.1113	bm9.8
.0401	.0220	.0787	.0256	.0813	th1.8
.0617	.0135	.0985	.0249	.0993	th2.8
.0574	.0135	.0685	.0221	.1046	th4.8
.0487	.0191	.0939	.0283	.0923	tm1.8
.0360	.0181	.0986	.0218	.0983	tm2.8
.0362	.0221	.0804	.0192	.0980	tm4.8
.0401	.0166	.1027	.0251	.0981	tm7.8
.0404	.0254	.0901	.0133	.1228	dh1.8
.0421	.0239	.0888	.0138	.1059	dh2.8
.0573	.0222	.0843	.0137	.1093	dh4.8
.0525	.0361	.0644	.0115	.1108	dm1.8
.0453	.0252	.0850	.0133	.1217	dm10
.0486	.0260	.0906	.0139	.1134	dm11
.0590	.0212	.0850	.0121	.1119	dm2.8
.0373	.0242	.0913	.0126	.1074	dm3.8
.0452	.0287	.0822	.0102	.1049	dm4.8
.0435	.0322	.0786	.0129	.1159	dm8.8
.0450	.0314	.0762	.0117	.1151	dm9.8
.0353	.0082	.0891	.0476	.0894	kh1.8
.0279	.0094	.1018	.0349	.0965	kh2.8
.0277	.0115	.0990	.0399	.0792	kh3.8

.0273	.0037	.0795	.0586	.0721	kh4.8
.0297	.0104	.0957	.0386	.0679	kh5.8
.0278	.0118	.0964	.0452	.0677	kh6.8
.0367	.0117	.0637	.0533	.0919	kh7.8
.0291	.0072	.0864	.0432	.0722	kh8.8
.0258	.0093	.0987	.0406	.0744	kh9.8
.0395	.0083	.0913	.0420	.0790	km1.8
.0324	.0083	.0821	.0373	.0844	km10
.0318	.0098	.0684	.0386	.0859	km11
.0391	.0093	.0781	.0466	.0985	km2.8
.0345	.0122	.0604	.0410	.0936	km3.8
.0271	.0111	.0704	.0435	.0798	km5.8
.0309	.0065	.0720	.0360	.0865	km6.8
.0320	.0088	.0765	.0470	.0852	km7.8
.0397	.0070	.0840	.0393	.0825	km8.8
.0320	.0089	.0809	.0355	.0878	km9.8
.0391	.0114	.1011	.0170	.1072	gh1.8
.0408	.0198	.1207	.0233	.1033	gh2.8
.0409	.0119	.1060	.0312	.0888	gh3.8
.0338	.0160	.0956	.0226	.1010	gh4.8
.0336	.0174	.0913	.0258	.1023	gh5.8
.0335	.0172	.0859	.0225	.1093	gh6.8
.0264	.0187	.0892	.0246	.1047	gh7.8
.0342	.0194	.0974	.0184	.1271	gh8.8
.0323	.0251	.0791	.0234	.1039	gh9.8
.0275	.0169	.0741	.0224	.1047	gm1.8
.0408	.0213	.0693	.0207	.1053	gm2.8
.0311	.0125	.0688	.0273	.1045	gm3.8
.0214	.0183	.0801	.0227	.1079	gm4.8
.0216	.0174	.0726	.0195	.1033	gm5.8
.0254	.0165	.0748	.0172	.0885	gm6.8
.0407	.0166	.0871	.0194	.0943	gm7.8
.0268	.0092	.1025	.0225	.0788	gm8.8
.0269	.0121	.0816	.0195	.0938	gm9.8

Table 7.2. Numerical data for the amplitude (dB) of the burst (B) of the class A and class B stops and the peak amplitude of the following vowel [a] (V).

B	V	
57	82	ph1.1
55	81	ph2.1
58	81	ph3.1
60	80	ph4.1
65	80	ph5.1
63	79	ph6.1
70	80	ph7.1
60	78	ph8.1
61	79	ph9.1
65	84	pm1.1
61	82	pm10.1
63	82	pm11.1
60	80	pm12.1
57	82	pm2.1
53	79	pm3.1
57	82	pm4.1
58	80	pm5.1
56	79	pm6.1
64	79	pm7.1
58	78	pm8.1
58	79	pm9.1
54	84	bash1.1
60	83	bash2.1
57	84	bash3.1
67	83	bash4.1
72	83	bash5.1
64	84	bash6.1
63	83	bash7.1
68	83	bash8.1
61	83	bash9.1
56	83	bm1.1
65	82	bm2.1
55	82	bm3.1
56	80	bm4.1
57	80	bm5.1
57	79	bm6.1
61	80	bm7.1
62	79	bm8.1
55	78	bm9.1
64	83	tath1.1
64	83	tath2.1
66	83	tath3.1
67	84	tath4.1
67	83	tath5.1
66	83	tath6.1
68	83	tath7.1
66	83	tath8.1
67	82	tath9.1
65	82	tatm1.1
66	83	tatm2.1
67	81	tatm3.1
69	81	tatm4.1
66	82	tatm5.1
66	83	tatm6.1
64	80	tatm7.1
64	82	tatm8.1
65	83	tatm9.1
57	82	dath1.1
59	83	dath2.1
60	83	dath3.1
59	82	dath4.1
65	82	dath5.1
58	83	dath6.1
62	82	dath7.1
59	82	dath8.1
62	83	dath9.1
57	83	datm1.1
54	83	datm2.1
60	82	datm3.1
53	82	datm4.1
58	81	datm5.1
67	81	datm6.1
66	83	kakh1.1
68	82	kakh2.1
69	82	kakh3.1
67	84	kakh4.1
69	82	kakh5.1
67	83	kakh6.1
70	81	kakh7.1
67	81	kakh8.1
68	81	kakh9.1
71	82	kakm1.1
68	84	kakm2.1
70	85	kakm3.1
68	81	kakm4.1
66	81	kakm5.1
66	82	kakm6.1
67	83	kakm7.1
64	83	kakm8.1
66	82	kakm9.1
61	83	gakh1.1
65	82	gakh2.1
60	82	gakh3.1
63	83	gakh4.1
63	82	gakh5.1
64	83	gakh6.1
66	83	gakh7.1
62	82	gakh8.1
62	83	gakh9.1
64	83	gakm1.1
64	82	gakm2.1
61	81	gakm3.1
59	82	gakm4.1
62	80	gakm5.1
63	81	gakm6.1
64	82	gakm6.1
60	82	gakm7.1
64	82	gakm8.1
60	82	gakm9.1
60	82	ph1.2
61	80	ph2.2
74	85	ph3.2
62	81	ph4.2
65	82	ph5.2
64	81	ph6.2
64	79	ph7.2
68	79	ph8.2
61	80	ph9.2
65	84	pm1.2
62	82	pm2.2
63	78	pm3.2
64	80	pm4.2
65	78	pm5.2
62	79	pm6.2
66	82	pm7.2
65	77	pm8.2
66	80	pm9.2
67	83	bh1.2
67	82	bh2.2
60	82	bh3.2
64	83	bh4.2
56	83	bh5.2
57	83	bh6.2
70	83	bh7.2

64	82	bh8.2
56	82	bh9.2
60	85	bm1.2
59	84	bm2.2
64	84	bm3.2
61	85	bm4.2
65	82	bm5.2
59	83	bm6.2
68	83	bm7.2
66	80	bm8.2
63	83	bm9.2
70	84	th1.2
70	82	th2.2
69	84	th3.2
74	83	th4.2
71	82	th5.2
73	84	th6.2
67	85	th7.2
70	83	th8.2
74	84	th9.2
69	83	tm1.2
70	82	tm2.2
68	82	tm3.2
69	82	tm4.2
68	81	tm5.2
74	83	tm6.2
73	82	tm7.2
69	83	tm8.2
74	81	tm9.2
62	82	dath1.2
71	83	dath2.2
76	83	dath3.2
74	83	dath4.2
63	84	dath5.2
68	84	dath6.2
68	84	dath7.2
70	85	dath8.2
71	83	dath9.2
72	85	dm1.2
67	83	dm2.2
70	85	dm3.2
65	85	dm4.2
63	84	dm5.2
67	84	dm6.2
64	84	dm7.2
71	85	dm8.2
69	85	dm9.2
73	84	kh1.2
71	83	kh2.2
71	83	kh3.2
75	86	kh4.2
74	85	kh5.2
69	83	kh6.2
75	83	kh7.2
77	84	kh8.2
72	84	kh9.2
75	79	km1.2
75	83	km2.2
70	83	km3.2
71	84	km4.2
73	84	km5.2
71	83	km6.2
72	82	km7.2
73	83	km8.2
64	82	km9.2
76	83	gakh1.2
76	84	gakh2.2
80	84	gakh3.2
76	84	gakh4.2
73	82	gakh5.2
73	84	gakh6.2
72	84	gakh7.2
78	84	gakh8.2
75	84	gakh9.2
73	85	gm1.2
76	84	gm2.2
72	84	gm3.2
74	84	gm4.2
75	85	gm5.2
67	84	gm6.2
67	84	gm7.2
71	85	gm8.2
74	85	gm9.2
66	78	ph1.3
68	77	ph2.3
67	75	ph3.3
69	77	ph4.3
71	77	ph5.3
68	77	ph6.3
68	76	ph7.3
66	78	ph8.3
71	77	ph9.3
62	77	pm1.3
63	75	pm2.3
68	78	pm3.3
65	77	pm4.3
59	75	pm5.3
66	78	pm6.3
61	77	pm7.3
66	76	pm8.3
69	81	bh1.3
65	81	bh10.3
67	81	bh11.3
67	79	bh12.3
68	81	bh2.3
69	81	bh3.3
70	83	bh4.3
67	80	bh5.3
62	81	bh6.3
71	81	bh7.3
64	80	bh8.3
68	79	bh9.3
63	79	bm1.3
63	79	bm2.3
61	80	bm3.3
66	79	bm4.3
66	78	bm5.3
66	77	bm6.3
59	77	bm7.3
64	77	bm8.3
66	79	bm9.3
79	79	th1.3
73	80	th2.3
71	80	th3.3
72	81	th4.3
77	80	th5.3
76	79	th6.3
70	81	th7.3
73	78	th8.3
71	79	th9.3
78	78	tm1.3
73	79	tm10.3
68	80	tm11.3
74	78	tm12.3
79	79	tm2.3
71	76	tm3.3
78	80	tm4.3
70	76	tm5.3
75	76	tm6.3
69	77	tm7.3
75	78	tm8.3
76	81	tm9.3
70	79	dh1.3
66	79	dh2.3
62	80	dh3.3
64	80	dh4.3
71	82	dh5.3
74	80	dh6.3
64	79	dh7.3
66	81	dh8.3
68	82	dh9.3
78	82	dm1.3
75	80	dm2.3
77	81	dm3.3
80	81	dm4.3
76	81	dm5.3
67	80	dm6.3
78	79	dm7.3
74	81	dm8.3
63	80	dm9.3
68	79	kh1.3
63	79	kh2.3
63	80	kh3.3
65	77	kh4.3
63	79	kh5.3
64	77	kh6.3
66	81	kh7.3
66	79	kh8.3
68	77	kh9.3
72	79	km1.3
72	78	km2.3
79	79	km3.3
65	78	km4.3
68	81	km5.3
74	78	km6.3
69	77	km7.3
70	79	km8.3
68	79	km9.3
69	77	gh1.3
70	80	gh2.3
67	81	gh3.3
60	80	gh4.3
67	82	gh5.3
70	83	gh6.3
68	82	gh7.3
67	84	gh8.3
67	82	gh9.3
65	81	gm1.3
70	82	gm2.3
71	83	gm3.3
71	79	gm4.3
70	81	gm5.3
70	80	gm6.3
66	83	gm7.3
68	83	gm8.3
69	83	gm9.3
77	81	ph1.4
74	79	ph2.4
76	80	ph3.4
72	80	ph4.4
73	80	ph5.4
72	82	ph6.4
72	80	ph7.4
77	82	ph8.4
68	80	ph9.4
78	77	pm1.4
75	78	pm2.4
71	78	pm3.4
75	75	pm4.4
69	77	pm5.4
74	79	pm6.4
74	77	pm7.4
71	79	pm8.4
73	80	pm9.4
65	78	bh1.4
68	77	bh2.4
66	77	bh3.4
63	79	bh4.4
69	79	bh5.4
68	79	bh6.4
70	78	bh7.4
71	77	bh8.4
69	79	bh9.4
67	79	bm1.4
68	77	bm2.4
70	78	bm3.4
70	78	bm4.4
67	79	bm5.4
69	79	bm6.4
71	79	bm7.4
61	78	bm8.4
60	77	bm9.4
79	80	th1.4
72	81	th2.4
68	81	th3.4
66	80	th4.4
69	81	th5.4
71	81	th6.4
82	80	th7.4
74	80	th8.4
67	82	th9.4
78	79	tm1.4
72	78	tm2.4
70	80	tm3.4
74	80	tm4.4

70	78	tm5.4
72	79	tm6.4
71	79	tm7.4
70	80	tm8.4
67	79	tm9.4
68	78	dh1.4
71	78	dh2.4
73	78	dh3.4
69	78	dh4.4
72	79	dh5.4
71	79	dh6.4
72	79	dh7.4
64	78	dh8.4
64	77	dh9.4
70	79	dm1.4
69	79	dm2.4
70	78	dm3.4
63	79	dm4.4
75	79	dm5.4
70	78	dm6.4
70	81	dm7.4
71	77	dm8.4
67	77	dm9.4
72	80	kh1.4
70	80	kh2.4
72	80	kh3.4
73	79	kh4.4
68	81	kh5.4
70	80	kh6.4
73	80	kh7.4
72	80	kh8.4
66	80	kh9.4
70	79	km1.4
71	77	km2.4
71	80	km3.4
75	79	km4.4
74	79	km5.4
76	79	km6.4
71	76	km7.4
72	79	km8.4
74	80	km9.4
78	80	gh1.4
73	78	gh10.4
71	78	gh11.4
76	78	gh12.4
76	79	gh2.4
74	79	gh3.4
71	79	gh4.4
67	78	gh5.4
75	77	gh6.4
75	78	gh7.4
74	78	gh8.4
73	77	gh9.4
78	79	gm1.4
67	79	gm2.4
70	78	gm3.4
67	78	gm4.4
70	79	gm5.4
68	77	gm6.4
73	79	gm7.4
69	79	gm8.4
72	80	gm9.4
70	83	ph1.5
69	83	ph2.5
66	83	ph3.5
65	81	ph4.5
66	83	ph5.5
71	82	ph6.5
62	82	ph7.5
65	82	ph8.5
61	83	ph9.5
65	79	pm1.5
74	82	pm2.5
52	82	pm3.5
70	81	pm4.5
69	82	pm5.5
71	81	pm6.5
69	80	pm7.5
71	82	pm8.5
66	80	pm9.5
64	83	bh1.5
71	84	bh2.5
65	84	bh3.5
65	83	bh4.5
65	84	bh5.5
64	83	bh6.5
56	83	bh7.5
66	83	bh8.5
66	83	bh9.5
62	82	bm1.5
56	83	bm2.5
55	81	bm3.5
60	82	bm4.5
56	83	bm5.5
57	83	bm6.5
64	82	bm7.5
62	82	bm8.5
54	83	bm9.5
71	82	th1.5
79	85	th2.5
71	84	th3.5
73	82	th4.5
70	83	th5.5
71	82	th6.5
75	83	th7.5
76	82	th8.5
70	83	th9.5
74	77	tm1.5
70	81	tm10.5
77	79	tm2.5
75	80	tm3.5
74	82	tm4.5
71	78	tm5.5
76	82	tm6.5
78	82	tm7.5
74	82	tm8.5
72	82	tm9.5
76	84	dh1.5
71	84	dh10.5
78	84	dh11.5
71	85	dh12.5
75	83	dh2.5
78	84	dh3.5
73	84	dh4.5
78	85	dh5.5
73	85	dh6.5
72	85	dh7.5
79	84	dh8.5
68	84	dh9.5
75	84	dm1.5
73	84	dm2.5
79	85	dm3.5
72	84	dm4.5
76	85	dm5.5
73	84	dm6.5
75	84	dm7.5
70	85	dm8.5
75	84	dm9.5
73	81	kh1.5
76	83	kh10.5
71	81	kh11.5
74	83	kh12.5
76	83	kh2.5
76	83	kh3.5
74	82	kh4.5
80	82	kh5.5
76	82	kh6.5
71	81	kh7.5
74	82	kh8.5
74	79	kh9.5
75	81	km1.5
72	80	km2.5
71	80	km3.5
79	81	km4.5
77	80	km5.5
71	80	km6.5
77	80	km7.5
78	82	km8.5
76	79	km9.5
79	83	gh1.5
80	84	gh10.5
77	84	gh11.5
76	83	gh12.5
79	85	gh2.5
81	84	gh3.5
74	84	gh4.5
77	85	gh5.5
80	84	gh6.5
78	84	gh7.5
77	84	gh8.5
78	84	gh9.5
77	83	gm1.5
78	84	gm2.5
78	83	gm3.5
77	84	gm4.5
76	84	gm5.5
79	83	gm6.5
79	84	gm7.5
73	84	gm8.5
76	83	gm9.5
60	82	ph1.6
69	81	ph2.6
66	78	ph3.6
66	82	ph4.6
59	79	ph5.6
54	80	ph6.6
60	80	ph7.6
62	79	ph8.6
65	81	ph9.6
63	81	pm1.6
70	80	pm2.6
61	82	pm3.6
63	81	pm4.6
67	79	pm5.6
62	80	pm6.6
67	79	pm7.6
62	79	pm8.6
62	78	pm9.6
58	84	bh1.6
57	84	bh2.6
66	84	bh3.6
56	83	bh4.6
55	83	bh5.6
58	84	bh6.6
50	84	bh7.6
54	82	bh8.6
54	83	bh9.6
55	84	bm1.6
58	84	bm2.6
50	83	bm3.6
52	82	bm4.6
57	84	bm5.6
70	82	bm6.6
55	84	bm7.6
56	83	bm8.6
54	84	bm9.6
71	83	th1.6
71	83	th2.6
73	82	th3.6
69	84	th4.6
66	83	th5.6
66	84	th6.6
69	85	th7.6
66	84	th8.6
64	83	th9.6
71	82	tm1.6
68	80	tm2.6
70	83	tm3.6
67	83	tm4.6
66	82	tm5.6
69	81	tm6.6
71	81	tm7.6
67	81	tm8.6
66	83	tm9.6
65	83	dh1.6
68	85	dh2.6
68	85	dh3.6
72	85	dh4.6
66	85	dh5.6
64	85	dh6.6
65	82	dh7.6
71	85	dh8.6
64	85	dh9.6
68	85	dm1.6
68	85	dm2.6

69	85	dm3.6
69	85	dm4.6
71	83	dm5.6
68	84	dm6.6
70	85	dm7.6
62	84	dm8.6
71	84	dm9.6
70	81	kh1.6
73	80	kh2.6
72	81	kh3.6
71	81	kh4.6
70	80	kh5.6
68	79	kh6.6
74	82	kh7.6
66	83	kh8.6
75	80	kh9.6
76	80	km1.6
74	80	km2.6
72	80	km3.6
73	81	km4.6
75	80	km5.6
70	80	km6.6
67	82	km7.6
71	79	km8.6
71	80	km9.6
81	85	gh1.6
69	85	gh2.6
76	84	gh3.6
73	84	gh4.6
68	83	gh5.6
71	84	gh6.6
72	84	gh7.6
73	84	gh8.6
70	83	gh9.6
70	84	gm1.6
72	85	gm2.6
72	85	gm3.6
66	83	gm4.6
68	83	gm5.6
71	83	gm6.6
71	83	gm7.6
71	81	gm8.6
70	82	gm9.6
80	85	ph1.7
79	85	ph2.7
83	84	ph3.7
77	85	ph4.7
71	85	ph5.7
73	84	ph6.7
84	85	ph7.7
68	84	ph8.7
73	83	ph9.7
77	85	pm1.7
69	84	pm2.7
68	84	pm3.7
82	84	pm4.7
71	84	pm5.7
78	83	pm6.7
81	84	pm7.7
62	82	pm8.7
79	85	pm9.7
71	85	bh1.7
73	85	bh10.7
66	85	bh11.7
71	85	bh12.7
67	85	bh2.7
68	85	bh3.7
74	84	bh4.7
63	84	bh5.7
69	84	bh6.7
66	84	bh7.7
68	85	bh8.7
64	84	bh9.7
74	84	bm1.7
71	85	bm10.7
72	84	bm11.7
66	84	bm12.7
72	85	bm2.7
65	83	bm3.7
72	85	bm4.7
71	83	bm5.7
71	84	bm6.7
83	85	bm7.7
69	84	bm8.7
75	83	bm9.7
79	84	th1.7
76	85	th10.7
77	83	th11.7
76	83	th12.7
77	84	th2.7
73	84	th3.7
75	84	th4.7
72	84	th5.7
74	84	th6.7
75	83	th7.7
74	83	th8.7
73	84	th9.7
76	84	tm1.7
71	84	tm2.7
72	84	tm3.7
79	84	tm4.7
74	84	tm5.7
77	84	tm6.7
75	84	tm7.7
75	84	tm8.7
78	84	tm9.7
76	84	dh1.7
73	85	dh2.7
75	85	dh3.7
78	84	dh4.7
74	84	dh5.7
76	85	dh6.7
75	83	dh7.7
71	84	dh8.7
75	82	dh9.7
75	85	dm1.7
74	85	dm2.7
72	84	dm3.7
77	84	dm4.7
73	84	dm5.7
73	83	dm6.7
78	84	dm7.7
72	83	dm8.7
75	84	dm9.7
77	82	kh1.7
74	83	kh2.7
74	84	kh3.7
72	83	kh4.7
76	83	kh5.7
72	83	kh6.7
75	84	kh7.7
75	83	kh8.7
74	83	kh9.7
73	85	km1.7
79	85	km10.7
76	83	km11.7
77	84	km12.7
80	85	km2.7
75	84	km3.7
76	85	km4.7
75	84	km5.7
76	83	km6.7
70	82	km7.7
75	82	km8.7
74	80	km9.7
77	83	gh1.7
79	83	gh2.7
78	83	gh3.7
75	82	gh4.7
75	82	gh5.7
77	83	gh6.7
73	80	gh7.7
70	79	gh8.7
75	80	gh9.7
73	82	gm1.7
74	81	gm2.7
78	82	gm3.7
74	80	gm4.7
73	81	gm5.7
76	81	gm6.7
76	81	gm7.7
71	82	gm8.7
70	80	gm9.7
68	83	ph1.8
59	83	ph2.8
62	84	ph3.8
63	84	ph4.8
67	84	ph5.8
74	84	ph6.8
62	82	ph7.8
64	82	ph8.8
67	83	ph9.8
68	84	pm1.8
73	84	pm2.8
76	84	pm3.8
66	85	pm4.8
62	84	pm5.8
72	84	pm6.8
66	83	pm7.8
66	84	pm8.8
64	84	pm9.8
71	85	bh1.8
67	84	bh2.8
70	85	bh3.8
66	85	bh4.8
68	85	bh5.8
69	85	bh6.8
58	85	bh7.8
59	85	bh8.8
69	85	bh9.8
60	83	bm1.8
60	84	bm2.8
60	84	bm3.8
60	83	bm4.8
64	83	bm5.8
65	83	bm6.8
61	84	bm7.8
58	84	bm8.8
63	84	bm9.8
70	84	th1.8
65	84	th2.8
68	83	th3.8
68	84	th4.8
66	84	th5.8
68	84	th6.8
70	84	th7.8
72	85	tm1.8
75	84	tm2.8
70	84	tm3.8
72	86	tm4.8
67	85	tm5.8
65	85	tm6.8
69	85	tm7.8
65	85	tm8.8
69	84	tm9.8
65	84	dh1.8
65	84	dh2.8
66	84	dh3.8
64	84	dh4.8
66	84	dh5.8
63	85	dh6.8
63	84	dh7.8
66	85	dh8.8
60	84	dh9.8
64	84	dm1.8
59	84	dm10.8
70	84	dm11.8
69	83	dm12.8
59	84	dm13.8
62	84	dm2.8
62	84	dm3.8
63	83	dm4.8
63	85	dm5.8
61	83	dm6.8
60	85	dm7.8
68	83	dm8.8
63	83	dm9.8
60	82	kh1.8
58	81	kh2.8
61	82	kh3.8
58	83	kh4.8
59	83	kh5.8
58	82	kh6.8
56	82	kh7.8
62	83	kh8.8

58	84	kh9.8
66	83	km1.8
63	84	km10.8
62	84	km11.8
67	84	km2.8
64	83	km3.8
60	83	km4.8
65	83	km5.8
60	83	km6.8
62	84	km7.8
64	84	km8.8
62	84	km9.8
68	84	gh1.8
63	84	gh2.8
64	84	gh3.8
64	84	gh4.8
64	84	gh5.8
65	84	gh6.8
64	84	gh7.8
60	84	gh8.8
62	84	gh9.8
58	83	gm1.8
58	83	gm2.8
59	84	gm3.8
60	82	gm4.8
57	83	gm5.8
57	83	gm6.8
65	84	gm7.8
62	84	gm8.8
61	83	gm9.8

Table 7.3. Numerical data for the frequencies (Hz) of the first three formants (F1, F2, and F3) of the vowel [a] following the class A [t] and class B [d].

F1	F2	F3	
661	1624	2938	th1.1
613	1567	2836	th3.1
654	1604	2904	th4.1
640	1582	2661	th5.1
638	1566	2710	th6.1
647	1593	2865	th7.1
620	1603	2815	th8.1
618	1553	2812	th9.1
697	1655	2638	tm1.1
641	1588	2772	tm3.1
647	1635	2817	tm4.1
652	1678	2974	tm5.1
657	1669	2974	tm6.1
604	1558	2811	tm7.1
684	1670	2759	tm8.1
626	1599	2843	tm9.1
661	1586	2752	dh1.1
706	1599	2810	dh2.1
731	1733	2822	dh3.1
650	1616	2827	dh4.1
715	1606	2648	dh5.1
695	1647	2915	dh6.1
728	1666	2757	dh7.1
658	1586	2636	dh8.1
705	1626	2656	dh9.1
644	1708	2902	dm1.1
660	1620	2965	dm2.1
634	1604	2930	dm3.1
615	1641	2693	dm4.1
638	1640	2807	dm5.1
625	1638	2687	dm6.1
759	1902	2983	th1.2
817	1878	2863	th2.2
775	1758	2930	th4.2
•	1688	2778	th5.2
794	1909	3284	th6.2
760	1998	3071	th7.2
794	1585	2661	th8.2
789	1832	2802	th9.2
784	1787	2849	tm1.2
806	1927	2804	tm3.2
761	2015	2840	tm4.2
818	1842	2899	tm7.2
750	1883	2928	tm8.2
760	2044	2979	tm9.2
756	2001	2990	dh1.2
747	1928	2919	dh2.2
722	2014	3029	dh3.2
771	1890	2976	dh4.2
753	1883	3009	dh5.2
721	1777	2910	dh6.2
752	2012	2948	dh7.2
750	1849	2803	dh8.2
743	1898	2861	dh9.2
772	1900	3334	dm1.2
759	1963	2688	dm2.2
683	•	3116	dm3.2
719	1907	3022	dm4.2
789	1788	2886	dm5.2
756	1953	3040	dm6.2
751	1747	2896	dm7.2
713	1955	2956	dm8.2
737	1775	2851	dm9.2
597	1565	2558	th1.3
581	1583	2635	th2.3
521	1554	2561	th3.3
584	1581	2554	th4.3
606	1503	2666	th5.3
599	1524	2669	th6.3
601	1562	2495	th7.3
549	1542	2566	th8.3
649	1572	2691	tm1.3
580	1571	2540	tm10.3
569	1587	2570	tm11.3
628	1521	2691	tm2.3
616	1514	2755	tm3.3
643	1515	2608	tm4.3
621	1572	2700	tm5.3
610	1552	2730	tm6.3
564	1525	2523	tm7.3
580	1484	2571	tm8.3
634	1538	2589	tm9.3
584	1524	2685	dh1.3
603	1536	2551	dh2.3
586	1487	2544	dh3.3
554	1568	2577	dh4.3
658	1474	2615	dh5.3
596	1534	2638	dh6.3
592	1562	2754	dh7.3
595	1483	2511	dh8.3
611	1493	2620	dh9.3
631	1474	2628	dm1.3
648	1479	2587	dm2.3
583	1498	3128	dm3.3
606	1503	2693	dm4.3
529	1534	2587	dm5.3
553	1512	2585	dm6.3
600	1530	2653	dm7.3
567	1477	2557	dm8.3
592	1469	2522	dm9.3
572	1793	3114	th1.4
604	1776	3239	th2.4
605	1808	3221	th3.4
562	1685	2951	th4.4
553	1770	3060	th5.4
557	1769	3121	th6.4
494	1766	3057	th7.4
545	1701	3054	th8.4
576	1773	3090	th9.4
468	1737	2883	tm2.4
480	1773	3074	tm3.4
506	1688	2950	tm4.4
466	1707	3095	tm5.4

524	1765	2929	tm6.4
528	1577	2857	tm7.4
494	1698	3050	tm8.4
•	1708	3014	tm9.4
621	1952	2902	dh1.4
654	1702	2854	dh2.4
677	1823	2880	dh3.4
583	1701	2906	dh4.4
605	1648	2924	dh5.4
•	1617	2779	dh6.4
630	1607	2824	dh7.4
643	1757	2968	dh8.4
591	1668	2933	dh9.4
•	1759	3022	dm1.4
584	1721	3007	dm2.4
537	1661	2945	dm3.4
568	1665	2892	dm4.4
•	1678	2947	dm5.4
•	1616	2829	dm6.4
648	1552	2924	dm7.4
531	1572	2827	dm8.4
609	1594	2902	dm9.4
579	1656	3162	th1.5
641	1763	3034	th2.5
582	1573	2833	th3.5
573	1559	3165	th4.5
567	1950	3146	th5.5
564	1667	3144	th6.5
550	1581	2997	th7.5
521	2044	3300	th8.5
556	1666	3181	th9.5
559	1623	2708	tm1.5
488	1363	3084	tm10.5
633	1640	3178	tm2.5
487	1353	2973	tm3.5
561	1664	3185	tm4.5
456	•	3192	tm5.5
613	1656	3073	tm6.5
490	1506	3092	tm7.5
559	1661	3180	tm8.5
558	1581	3058	tm9.5
713	1768	•	dh1.5
626	1842	3112	dh10.5
627	1682	2979	dh11.5
616	1854	2918	dh12.5
693	1685	3086	dh2.5
680	1915	2958	dh3.5
668	2000	3207	dh4.5
706	2031	3124	dh5.5
664	2016	3141	dh6.5
615	1662	2641	dh7.5
589	1667	2746	dh8.5
609	1915	3137	dh9.5
589	1564	3025	dm1.5
569	1562	3030	dm2.5
638	1717	2914	dm3.5
593	1599	2439	dm4.5
591	1640	2754	dm5.5
•	1404	3053	dm6.5
606	1670	2989	dm7.5
571	1751	3129	dm8.5
560	1415	2558	dm9.5
575	1580	2801	th1.6
596	1602	2725	th2.6
654	1610	2770	th3.6
662	1652	2736	th4.6
645	1603	2765	th5.6
661	1575	2849	th6.6
663	1834	2879	th7.6
637	1657	2764	th8.6
621	1575	2712	th9.6
627	1583	2734	tm1.6
652	1548	2577	tm2.6
635	1537	2643	tm3.6
662	1807	2828	tm4.6
653	1611	2641	tm5.6
627	1521	2664	tm6.6
624	1485	2583	tm7.6
628	1527	2579	tm8.6
710	1846	2769	tm9.6
661	1635	2700	dh1.6
660	1638	2850	dh2.6
612	1608	2805	dh3.6
617	1616	2694	dh4.6
621	1667	2657	dh5.6
639	1858	2752	dh8.6
647	1923	2692	dm2.6
664	1997	3014	dm3.6
657	1652	2508	dm5.6
627	1649	2655	dm7.6
631	1565	2605	dm8.6
623	1727	2698	dm9.6
766	1787	2908	th5.7
755	1834	3087	th6.7
786	•	3242	th7.7
816	1679	2756	th8.7
819	1930	3025	th9.7
•	2028	3016	tm1.7
799	•	3083	tm7.7
762	1933	3320	tm8.7
784	2034	3395	dh1.7
•	1829	3332	dh10.7
•	1898	3299	dh7.7
798	1951	3390	dh8.7
747	1823	3311	dh9.7
798	•	•	dm1.7
760	1913	•	dm2.7
795	1684	•	dm3.7
792	1948	•	dm4.7
772	1905	•	dm5.7
778	1958	•	dm6.7
796	1972	3386	dm7.7
764	1941	•	dm8.7
741	1892	3362	dm9.7
687	1537	2795	th1.8
684	1674	2832	th2.8
650	1577	2850	th3.8
705	1604	2803	th4.8
671	1547	2839	th5.8
703	1548	2805	th6.8
710	1560	2853	th7.8
663	1599	2847	tm1.8
668	1553	2888	tm2.8
666	1577	2946	tm3.8
677	1655	2823	tm4.8
655	1571	2741	tm5.8
675	1663	2850	tm6.8
725	1784	2943	tm7.8
714	1853	2946	tm8.8
664	1687	2776	tm9.8
735	1568	3024	dh1.8
707	1563	2938	dh2.8
739	1625	3068	dh3.8
722	1668	2813	dh4.8
689	1768	3072	dh5.8
725	1677	2959	dh6.8
684	1629	2968	dh7.8
689	1619	2984	dh8.8
651	1617	3004	dh9.8
621	1646	2861	dm1.8
645	1653	2962	dm10.8
637	1596	2962	dm11.8
689	1549	2720	dm12.8
676	1551	2863	dm13.8
627	1596	2856	dm2.8
666	1513	2864	dm3.8
627	1572	2923	dm4.8

662	1589	2892	dm5.8
636	1605	2952	dm6.8
628	1610	2882	dm7.8
634	1571	2858	dm8.8
652	1510	2870	dm9.8

Table 7.4. Numerical data for the bandwidths (Hz) of the first four formants (F1, F2, F3, and F4) of the vowel [a] following the class A [t] and class B [d].

F1	F2	F3	F4	
91	268	862	495	th1.1
75	219	348	650	th3.1
87	243	662	696	th4.1
90	399	878	444	th5.1
86	335	•	361	th6.1
84	215	419	484	th7.1
73	200	484	427	th8.1
98	235	568	457	th9.1
120	510	632	694	tm1.1
107	200	403	211	tm3.1
126	152	386	886	tm4.1
154	168	419	475	tm5.1
133	174	537	446	tm6.1
102	177	403	336	tm7.1
112	402	564	297	tm8.1
155	417	635	369	tm9.1
101	179	270	358	dh1.1
48	180	277	356	dh2.1
71	391	399	600	dh3.1
50	141	671	590	dh4.1
71	397	393	781	dh5.1
45	276	380	•	dh6.1
87	422	321	658	dh7.1
78	307	270	224	dh8.1
87	371	453	247	dh9.1
80	372	697	880	dm1.1
48	205	557	753	dm2.1
62	176	119	467	dm3.1
91	353	207	302	dm4.1
110	172	318	182	dm5.1
130	379	480	161	dm6.1
54	397	451	453	th1.2
160	457	549	309	th2.2
70	265	269	527	th4.2
•	474	887	496	th5.2
101	121	296	812	th6.2
36	366	289	•	th7.2
97	374	308	553	th8.2
68	252	573	•	th9.2
127	435	730	307	tm1.2
144	468	619	358	tm3.2
96	460	440	256	tm4.2
141	473	477	287	tm7.2
81	398	453	386	tm8.2
174	233	574	398	tm9.2
73	125	133	766	dh1.2
60	112	125	666	dh2.2
99	172	193	342	dh3.2
41	172	147	549	dh4.2
43	156	296	722	dh5.2
74	343	319	617	dh6.2
48	124	267	449	dh7.2
69	259	173	632	dh8.2
41	238	326	665	dh9.2
109	656	538	•	dm1.2
36	409	•	750	dm2.2
68	•	362	301	dm3.2
111	165	436	329	dm4.2
49	284	469	619	dm5.2
44	84	246	397	dm6.2
93	430	378	460	dm7.2
76	202	268	595	dm8.2
35	328	390	519	dm9.2
95	156	409	637	th1.3
66	99	159	571	th2.3
79	109	360	312	th3.3
132	186	534	552	th4.3
98	178	217	524	th5.3
96	202	194	484	th6.3
92	172	532	545	th7.3
85	110	388	378	th8.3
113	158	332	•	tm1.3
128	160	397	326	tm10.3
140	165	471	622	tm11.3
100	157	239	•	tm2.3
201	97	507	•	tm3.3
92	108	246	304	tm4.3
232	154	628	•	tm5.3
181	235	530	•	tm6.3
159	232	422	542	tm7.3
163	181	456	890	tm8.3
65	90	372	331	tm9.3
139	259	327	•	dh1.3
135	180	292	898	dh2.3
89	199	221	•	dh3.3
102	130	124	485	dh4.3
82	278	216	•	dh5.3
94	172	460	•	dh6.3
113	168	•	•	dh7.3
67	159	298	528	dh8.3
82	161	221	•	dh9.3
78	173	303	•	dm1.3
86	168	195	813	dm2.3
61	157	•	•	dm3.3
72	195	306	•	dm4.3
101	195	119	707	dm5.3
70	148	323	821	dm6.3
108	164	231	•	dm7.3
62	142	267	767	dm8.3
63	155	132	609	dm9.3
235	317	361	536	th1.4
171	370	267	217	th2.4
185	442	230	398	th3.4
230	•	298	284	th4.4
205	232	281	349	th5.4
258	615	398	255	th6.4
•	584	279	813	th7.4
185	342	384	434	th8.4
158	351	263	545	th9.4
•	181	648	222	tm2.4
•	180	364	349	tm3.4
240	315	488	430	tm4.4
•	149	398	•	tm5.4
261	297	329	260	tm6.4
147	309	338	344	tm7.4
•	532	212	362	tm8.4
•	145	427	•	tm9.4
•	570	195	364	dh1.4
•	265	185	518	dh2.4
•	315	86	322	dh3.4
161	127	255	280	dh4.4
151	167	229	346	dh5.4
•	288	286	607	dh6.4
128	380	304	770	dh7.4
•	323	168	194	dh8.4

186	217	259	209	dh9.4
•	246	149	324	dm1.4
205	147	271	227	dm2.4
196	179	211	208	dm3.4
172	279	242	282	dm4.4
•	398	474	420	dm5.4
•	339	254	319	dm6.4
62	289	270	423	dm7.4
•	463	350	•	dm8.4
141	168	333	583	dm9.4
77	266	117	504	th1.5
68	369	504	851	th2.5
42	208	420	745	th3.5
75	322	320	•	th4.5
156	536	410	464	th5.5
94	355	526	575	th6.5
100	486	678	575	th7.5
195	531	434	300	th8.5
139	551	744	633	th9.5
216	539	•	•	tm1.5
155	•	244	232	tm10.5
135	381	308	312	tm2.5
183	588	462	433	tm3.5
142	380	356	306	tm4.5
201	•	92	352	tm5.5
130	196	291	202	tm6.5
148	656	415	331	tm7.5
121	502	389	406	tm8.5
107	406	249	452	tm9.5
86	•	•	•	dh1.5
111	523	678	819	dh10.5
106	422	653	•	dh11.5
117	635	•	•	dh12.5
114	429	464	704	dh2.5
92	441	698	825	dh3.5
102	212	446	579	dh4.5
85	197	617	544	dh5.5
103	318	691	687	dh6.5
114	684	•	•	dh7.5
108	606	•	•	dh8.5
95	348	625	•	dh9.5
102	327	508	725	dm1.5
115	491	•	•	dm2.5
81	407	652	789	dm3.5
116	710	816	813	dm4.5
104	528	•	•	dm5.5
•	543	507	•	dm6.5
123	543	633	•	dm7.5
82	300	467	860	dm8.5
119	452	686	•	dm9.5
125	221	338	282	th1.6
187	473	286	328	th2.6
167	448	522	675	th3.6
195	391	847	586	th4.6
223	521	560	645	th5.6
168	432	489	497	th6.6
100	548	601	576	th7.6
96	455	431	409	th8.6
133	479	293	387	th9.6
169	282	451	246	tm1.6
166	365	486	204	tm2.6
99	292	385	291	tm3.6
95	530	520	668	tm4.6
112	196	328	295	tm5.6
103	522	375	383	tm6.6
168	397	522	246	tm7.6
146	445	423	303	tm8.6
117	627	623	722	tm9.6
82	329	377	151	dh1.6
99	216	390	552	dh2.6
85	227	576	412	dh3.6
87	465	593	307	dh4.6
85	715	547	448	dh5.6
56	401	689	493	dh8.6
58	473	•	514	dm2.6
59	375	737	613	dm3.6
135	783	529	249	dm5.6
70	361	430	400	dm7.6
64	312	339	252	dm8.6
77	349	594	281	dm9.6
132	585	661	379	th5.7
131	578	703	602	th6.7
136	•	•	•	th7.7
157	•	707	390	th8.7
163	521	792	492	th9.7
•	637	517	328	tm1.7
170	•	•	•	tm7.7
151	289	347	•	tm8.7
181	582	501	•	dh1.7
•	227	248	•	dh10.7
•	353	781	824	dh7.7
104	379	539	836	dh8.7
117	225	335	454	dh9.7
129	•	•	•	dm1.7
134	243	•	685	dm2.7
117	•	•	•	dm3.7
136	313	•	729	dm4.7
134	153	•	483	dm5.7
105	308	•	733	dm6.7
131	304	406	786	dm7.7
122	222	•	689	dm8.7
129	261	371	529	dm9.7
84	300	298	547	th1.8
83	496	733	•	th2.8
68	315	448	•	th3.8
95	512	518	874	th4.8
78	245	360	847	th5.8
93	338	322	558	th6.8
110	348	323	631	th7.8
81	285	320	•	tm1.8
90	403	400	•	tm2.8
70	432	348	•	tm3.8
86	457	398	337	tm4.8
77	360	341	408	tm5.8
89	446	365	310	tm6.8
77	451	398	463	tm7.8
80	475	609	560	tm8.8
72	581	572	739	tm9.8
141	327	281	512	dh1.8
88	250	294	560	dh2.8
127	464	332	628	dh3.8
150	605	659	•	dh4.8
129	474	277	448	dh5.8
129	522	398	702	dh6.8
109	504	346	601	dh7.8
125	378	292	485	dh8.8
106	408	296	407	dh9.8
183	316	368	536	dm1.8
161	258	240	476	dm10.8
172	292	239	434	dm11.8
118	578	358	396	dm12.8
133	472	288	292	dm13.8
146	271	264	628	dm2.8
143	313	236	535	dm3.8
137	168	218	482	dm4.8
117	377	300	382	dm5.8
141	188	334	441	dm6.8
164	304	393	620	dm7.8
150	321	233	372	dm8.8
119	252	229	359	dm9.8

Table 7.5. Numerical data for the amplitude (dB) of the first and second harmonics at the onset of the vowel [a] (A and B, respectively), at the middle of the vowel (C and D), and at the offset of the vowel (E and F) following the class A and class B stops.

A	B	C	D	E	F	
61	61	63	62	64	63	ph1.1
59	60	62	62	63	63	ph2.1
59	61	60	61	63	64	ph3.1
60	62	62	63	64	63	ph4.1
60	62	61	62	62	62	ph5.1
59	61	60	62	62	62	ph6.1
59	61	61	62	63	63	ph7.1
57	57	58	59	60	60	ph8.1
59	60	60	62	62	61	ph9.1
61	59	63	59	64	61	pm1.1
59	60	62	62	61	62	pm10.1
59	59	60	60	60	60	pm11.1
57	59	60	60	62	58	pm12.1
58	57	60	59	60	60	pm2.1
58	60	59	60	61	60	pm3.1
57	58	59	59	61	61	pm4.1
60	61	60	60	61	58	pm5.1
56	59	58	60	59	60	pm6.1
59	59	60	60	64	60	pm7.1
57	58	60	60	61	60	pm8.1
55	57	57	59	60	60	pm9.1
58	63	59	61	67	63	bh1.1
60	61	62	62	66	64	bh2.1
61	62	63	60	67	63	bh3.1
60	61	62	63	66	62	bh4.1
58	59	61	57	66	63	bh5.1
58	63	61	57	66	63	bh6.1
57	61	62	60	65	61	bh7.1
54	60	61	59	65	51	bh8.1
57	60	61	61	65	61	bh9.1
56	59	59	59	62	61	bm1.1
56	62	60	60	64	60	bm2.1
54	59	59	59	62	59	bm3.1
56	60	58	59	63	61	bm4.1
52	58	54	58	56	58	bm5.1
52	57	54	58	59	57	bm6.1
54	59	56	58	59	59	bm7.1
51	58	54	59	56	58	bm8.1
52	58	56	58	59	58	bm9.1
64	63	64	63	63	63	th1.1
64	64	64	62	63	63	th2.1
62	62	63	63	62	63	th3.1
65	65	65	64	63	65	th4.1
64	64	65	64	63	64	th5.1
64	64	64	64	62	64	th6.1
65	63	65	63	65	64	th7.1
63	64	63	63	64	63	th8.1
64	61	64	62	64	63	th9.1
60	61	59	59	59	60	tm1.1
62	61	62	60	60	61	tm2.1
60	61	59	61	58	60	tm3.1
62	63	61	63	60	62	tm4.1
62	64	61	63	60	62	tm5.1
62	61	61	61	59	61	tm6.1
61	61	60	61	59	61	tm7.1
61	60	61	60	60	60	tm8.1
60	63	60	63	59	62	tm9.1
56	61	58	61	60	62	dh1.1
56	61	57	58	58	60	dh2.1
56	62	60	60	61	63	dh3.1
55	60	56	61	57	62	dh4.1
54	60	57	60	57	60	dh5.1
54	59	58	61	57	61	dh6.1
59	61	59	61	60	61	dh7.1
56	61	57	60	58	60	dh8.1
57	62	59	61	58	59	dh9.1
58	62	59	61	58	60	dm1.1
55	62	58	62	57	60	dm2.1
57	61	58	59	57	59	dm3.1
56	61	56	60	57	59	dm4.1
55	60	56	60	56	59	dm5.1
57	61	57	61	57	61	dm6.1
63	64	64	64	67	64	kh1.1
62	64	59	63	62	63	kh2.1
63	62	63	62	63	62	kh3.1
62	63	62	60	61	61	kh4.1
61	60	60	60	60	60	kh5.1
59	60	60	60	60	61	kh6.1
63	63	62	62	62	63	kh7.1
62	62	61	61	62	62	kh8.1
62	61	60	62	60	63	kh9.1
61	57	59	54	59	56	km1.1
59	59	58	56	59	56	km2.1
59	61	58	61	59	58	km3.1
61	57	60	58	59	58	km4.1
58	58	57	58	58	59	km5.1
60	59	58	56	57	56	km6.1
60	59	59	59	59	60	km7.1
61	59	59	59	59	59	km8.1
59	58	58	57	58	57	km9.1
56	63	58	58	58	59	gh1.1
58	63	57	59	59	60	gh2.1
59	62	58	56	59	59	gh3.1
59	63	56	59	60	60	gh4.1
56	61	56	58	60	61	gh5.1
57	62	56	58	59	60	gh6.1
58	63	60	58	61	61	gh7.1
58	61	57	58	61	60	gh8.1
60	61	58	60	61	60	gh9.1
59	61	57	59	56	57	gm1.1
56	62	56	59	55	57	gm2.1
57	61	56	58	56	57	gm3.1
57	59	56	56	56	57	gm4.1
57	59	56	58	56	57	gm5.1
55	61	56	57	54	56	gm6.1
57	59	56	55	56	57	gm7.1
56	60	55	55	54	55	gm8.1
57	60	56	57	56	57	gm9.1
61	61	61	58	65	58	ph1.2
60	58	62	59	64	56	ph2.2
64	65	64	59	66	61	ph3.2
62	60	63	60	65	60	ph4.2
64	60	64	59	65	59	ph5.2
61	61	61	58	63	58	ph6.2
67	59	65	56	64	56	ph7.2
63	64	63	60	64	60	ph8.2
59	63	61	60	64	59	ph9.2
61	63	62	60	62	60	pm1.2
58	61	58	60	60	59	pm2.2
60	59	60	59	61	57	pm3.2
58	60	58	60	59	59	pm4.2
62	59	61	59	61	57	pm5.2
62	59	62	60	62	59	pm6.2
61	62	62	59	63	59	pm7.2
62	59	61	58	62	53	pm8.2
61	59	59	58	61	56	pm9.2
58	58	64	60	70	67	bh1.2
59	63	63	61	66	56	bh2.2
56	61	63	62	68	63	bh3.2
59	64	64	62	67	61	bh4.2
57	63	64	61	68	63	bh5.2
56	61	61	61	68	60	bh6.2
61	64	62	59	68	57	bh7.2
57	61	61	58	65	59	bh8.2

57	60	62	60	66	59	bh9.2
56	57	55	55	67	64	bm1.2
56	60	62	58	65	60	bm2.2
55	61	63	64	68	62	bm3.2
58	64	64	62	66	56	bm4.2
53	56	57	55	65	59	bm5.2
53	57	58	50	64	59	bm6.2
57	60	63	61	64	59	bm7.2
56	61	59	58	65	60	bm8.2
54	59	59	60	65	59	bm9.2
69	69	63	64	65	69	th1.2
69	63	65	62	66	67	th2.2
69	69	66	63	66	69	th3.2
68	66	64	60	64	65	th4.2
67	63	64	59	65	62	th5.2
70	71	68	62	64	65	th6.2
68	71	63	62	64	67	th7.2
67	64	64	60	65	65	th8.2
68	65	66	61	66	68	th9.2
65	63	64	60	60	61	tm1.2
67	62	64	61	61	62	tm2.2
67	64	65	61	62	59	tm3.2
65	64	62	61	62	64	tm4.2
66	61	61	59	61	60	tm5.2
68	64	65	63	63	62	tm6.2
67	63	64	61	62	62	tm7.2
66	68	64	62	61	62	tm8.2
70	63	65	63	63	61	tm9.2
61	63	60	61	61	64	dh1.2
60	64	61	60	63	65	dh2.2
63	65	62	61	62	64	dh3.2
62	65	59	57	61	63	dh4.2
60	63	62	60	63	64	dh5.2
62	66	64	63	63	66	dh6.2
62	63	60	61	61	66	dh7.2
62	65	61	60	65	67	dh8.2
60	63	56	58	60	60	dh9.2
66	71	65	65	65	68	dm1.2
63	66	60	59	63	65	dm2.2
62	70	63	65	63	65	dm3.2
65	70	62	64	65	64	dm4.2
61	62	62	60	63	60	dm5.2
61	66	61	63	64	67	dm6.2
63	67	63	64	63	65	dm7.2
62	68	62	63	62	66	dm8.2
61	66	61	60	64	64	dm9.2
69	65	66	58	66	63	kh1.2
68	69	63	60	66	62	kh2.2
68	60	66	57	65	63	kh3.2
64	68	67	58	66	64	kh4.2
70	65	68	60	67	61	kh5.2
68	65	66	57	66	62	kh6.2
67	59	65	55	65	63	kh7.2
70	61	66	53	64	61	kh8.2
68	65	66	53	66	60	kh9.2
66	55	64	57	60	58	km1.2
67	62	66	58	63	60	km2.2
64	64	64	52	61	58	km3.2
65	62	65	57	63	58	km4.2
66	60	65	60	62	57	km5.2
65	65	64	58	62	60	km6.2
66	65	63	56	61	59	km7.2
69	65	65	58	63	60	km8.2
67	63	64	57	60	59	km9.2
62	63	59	46	64	62	gh1.2
64	69	60	54	67	65	gh2.2
62	63	60	58	67	64	gh3.2
62	65	64	57	64	63	gh4.2
60	63	62	57	61	60	gh5.2
63	68	63	60	64	62	gh6.2
62	66	59	56	62	59	gh7.2
60	65	61	57	63	64	gh8.2
63	60	59	56	64	62	gh9.2
61	67	60	58	59	58	gm1.2
62	65	60	51	60	55	gm2.2
67	71	51	56	61	56	gm3.2
66	69	61	46	61	57	gm4.2
63	68	58	56	61	62	gm5.2
63	69	60	59	62	62	gm6.2
62	68	62	56	63	59	gm7.2
63	65	63	54	50	51	gm8.2
63	69	64	50	63	58	gm9.2
61	62	61	61	62	57	ph1.3
63	62	62	62	62	58	ph2.3
62	61	64	60	63	56	ph3.3
63	61	64	59	62	52	ph4.3
63	61	63	62	62	59	ph5.3
63	60	64	60	63	59	ph6.3
64	60	63	59	62	58	ph7.3
62	61	60	61	61	57	ph8.3
62	62	61	62	61	56	ph9.3
61	60	59	60	59	60	pm1.3
61	60	60	60	59	59	pm2.3
62	62	59	60	57	56	pm3.3
62	62	61	61	60	58	pm4.3
61	60	61	59	60	58	pm5.3
61	60	60	59	58	56	pm6.3
61	60	60	59	59	58	pm7.3
61	59	60	59	59	59	pm8.3
59	59	58	58	59	59	bh1.3
58	57	57	57	57	58	bh10.3
61	62	58	56	59	61	bh11.3
59	59	58	59	60	59	bh12.3
59	59	59	59	58	59	bh2.3
59	58	60	59	60	61	bh3.3
59	56	57	57	59	61	bh4.3
61	60	59	58	60	60	bh5.3
59	61	58	56	58	59	bh6.3
61	63	60	59	61	63	bh7.3
59	60	59	59	59	60	bh8.3
60	61	58	58	59	57	bh9.3
56	58	58	57	58	58	bm1.3
57	58	59	60	60	59	bm2.3
56	58	60	59	61	59	bm3.3
57	57	57	58	57	58	bm4.3
59	59	58	57	59	58	bm5.3
61	61	60	59	60	58	bm6.3
55	57	57	57	57	56	bm7.3
57	57	58	57	57	56	bm8.3
59	60	59	60	61	58	bm9.3
63	61	63	61	61	60	th1.3
63	63	63	63	63	64	th2.3
65	65	63	65	63	64	th3.3
65	64	63	64	64	64	th4.3
63	61	62	62	61	62	th5.3
62	63	61	62	61	62	th6.3
64	64	62	63	62	64	th7.3
62	62	62	62	61	61	th8.3
62	63	63	62	62	61	th9.3
64	59	62	59	60	59	tm1.3
64	62	62	61	62	59	tm10.3
64	62	62	61	61	58	tm11.3
64	61	64	61	63	58	tm12.3
63	60	61	59	61	58	tm2.3
62	56	60	58	60	57	tm3.3
63	59	62	60	62	61	tm4.3
63	58	62	59	60	58	tm5.3
63	58	62	58	61	58	tm6.3
64	61	62	61	61	59	tm7.3
65	59	65	60	63	60	tm8.3
64	61	61	62	62	61	tm9.3
60	61	60	60	59	61	dh1.3
60	62	60	60	58	60	dh2.3
61	62	59	61	59	63	dh3.3
59	62	59	61	58	52	dh4.3
62	61	59	58	61	61	dh5.3
60	62	59	60	59	62	dh6.3

58	62	59	62	58	60	dh7.3
61	63	61	62	61	63	dh8.3
62	61	61	60	61	61	dh9.3
58	57	57	56	58	59	dm1.3
59	58	57	56	58	57	dm2.3
59	62	59	60	59	60	dm3.3
59	57	58	56	58	58	dm4.3
61	61	61	61	62	62	dm5.3
59	60	59	59	60	59	dm6.3
58	58	58	57	58	58	dm7.3
60	61	59	58	59	59	dm8.3
59	60	58	56	58	57	dm9.3
61	59	60	59	60	58	kh1.3
61	62	60	61	59	60	kh2.3
62	61	60	60	59	59	kh3.3
59	59	59	59	59	59	kh4.3
61	61	60	61	61	60	kh5.3
60	59	60	59	60	59	kh6.3
59	61	58	59	58	59	kh7.3
60	61	59	60	59	59	kh8.3
59	58	58	58	58	57	kh9.3
56	53	56	51	55	52	km1.3
58	55	58	55	58	55	km2.3
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58	60	57	56	57	57	km9.3
57	56	57	54	56	53	gh1.3
57	57	56	56	56	55	gh2.3
59	58	58	57	57	56	gh3.3
58	56	57	54	56	55	gh4.3
59	59	59	56	57	57	gh5.3
59	59	57	58	57	56	gh6.3
60	57	58	55	58	55	gh7.3
61	58	56	57	57	57	gh8.3
61	58	57	56	58	55	gh9.3
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63	59	59	55	59	58	gm2.3
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61	60	57	57	58	55	gm7.3
63	60	59	57	59	59	gm8.3
61	58	59	57	58	56	gm9.3
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68	63	69	61	67	55	ph2.4
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67	68	69	62	69	49	ph5.4
71	63	72	59	70	49	ph6.4
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72	52	71	59	69	52	ph8.4
68	68	70	62	69	52	ph9.4
66	62	66	62	65	48	pm1.4
68	62	68	61	68	38	pm2.4
68	65	69	61	67	47	pm3.4
63	61	65	60	66	51	pm4.4
66	66	67	63	67	53	pm5.4
68	64	68	65	68	58	pm6.4
67	67	67	65	69	50	pm7.4
65	66	66	67	67	58	pm8.4
70	67	70	64	68	57	pm9.4
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62	64	65	64	65	49	bh2.4
63	65	60	64	66	46	bh3.4
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58	63	63	65	67	44	bh5.4
63	60	66	63	68	58	bh6.4
64	63	68	65	69	57	bh7.4
64	62	67	62	66	51	bh8.4
65	63	67	64	68	58	bh9.4
65	66	67	64	67	51	bm1.4
62	62	64	63	66	57	bm2.4
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65	65	65	61	67	49	bm9.4
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70	62	68	68	68	65	th7.4
67	68	67	68	67	63	th8.4
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68	66	67	66	66	65	tm6.4
68	66	67	65	64	63	tm7.4
68	67	68	65	66	61	tm8.4
68	66	69	65	69	64	tm9.4
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68	66	67	67	66	59	kh6.4
67	67	66	68	65	65	kh7.4
67	66	67	67	65	58	kh8.4
66	68	66	66	65	61	kh9.4
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68	67	68	67	66	62	km6.4
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68	67	68	67	66	63	km9.4
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66	68	68	63	67	54	gm1.4
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63	67	64	65	62	63	ph9.5
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67	65	68	67	65	59	pm8.5
67	65	66	67	64	61	pm9.5
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59	62	64	62	71	68	bh3.5
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60	63	69	68	67	61	bh9.5
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63	66	69	66	71	65	bm8.5
59	62	69	65	69	52	bm9.5
68	67	66	67	65	66	th1.5
69	71	67	67	68	68	th2.5
70	71	65	67	67	70	th3.5
69	68	65	68	66	68	th4.5
68	68	69	69	67	67	th5.5
69	68	66	68	63	67	th6.5
68	67	66	68	64	67	th7.5
69	69	70	68	68	68	th8.5
69	68	67	68	67	66	th9.5
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68	64	63	66	61	61	tm5.5
70	68	63	65	65	65	tm6.5
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70	67	68	68	66	67	tm8.5
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71	65	69	66	67	55	kh1.5
72	66	69	68	70	65	kh10.5
67	67	66	67	66	66	kh11.5
70	69	66	68	67	63	kh12.5
70	67	67	68	66	62	kh2.5
71	68	66	68	67	66	kh3.5
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68	66	65	66	61	61	kh9.5
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67	67	67	65	64	61	km7.5
68	66	68	67	68	61	km8.5
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64	66	68	66	67	62	gh9.5
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67	58	70	63	73	64	ph1.6
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57	63	64	59	69	60	bh5.6
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62	66	64	65	63	64	dm9.6
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67	62	66	58	64	58	km1.6
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75	66	74	64	73	60	ph1.7
71	66	71	65	73	58	ph2.7
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74	67	74	64	71	59	ph7.7
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63	64	72	67	72	62	bm8.7
63	60	64	65	66	62	bm9.7
72	67	68	61	72	68	th1.7
67	70	68	65	69	66	th10.7
71	68	69	67	69	66	th11.7
69	66	67	65	67	64	th12.7
72	69	66	61	70	64	th2.7
70	68	66	62	68	67	th3.7
71	66	66	63	69	67	th4.7
68	67	66	64	68	65	th5.7
64	68	65	66	69	66	th6.7
70	68	69	62	70	67	th7.7
67	68	66	65	68	66	th8.7
69	68	66	63	69	66	th9.7
73	64	71	64	72	66	tm1.7
71	66	67	64	70	66	tm2.7
72	67	69	62	71	66	tm3.7

74	63	69	64	71	66	tm4.7
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68	68	67	64	68	66	tm8.7
71	65	71	63	70	65	tm9.7
67	66	68	63	71	69	dh1.7
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65	59	68	63	70	65	dh7.7
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64	59	67	64	69	65	dh9.7
63	64	67	66	69	68	dm1.7
63	63	67	66	68	66	dm2.7
64	66	67	66	67	66	dm3.7
65	65	70	66	69	65	dm4.7
65	66	68	66	68	66	dm5.7
63	63	67	64	66	64	dm6.7
64	65	68	67	69	66	dm7.7
64	64	68	66	68	65	dm8.7
63	63	68	65	65	62	dm9.7
72	65	72	64	69	61	kh1.7
73	65	70	63	69	64	kh2.7
72	64	68	63	67	61	kh3.7
73	65	72	65	71	64	kh4.7
71	65	72	64	70	62	kh5.7
72	65	70	64	69	61	kh6.7
74	65	72	64	71	63	kh7.7
72	66	71	65	70	64	kh8.7
72	66	71	66	70	63	kh9.7
74	63	70	65	71	64	km1.7
74	65	71	64	65	61	km10.7
71	65	69	65	67	64	km11.7
71	66	69	65	68	66	km12.7
75	62	72	65	70	62	km2.7
73	66	71	66	69	64	km3.7
74	67	72	67	69	63	km4.7
74	67	72	66	69	66	km5.7
72	68	70	65	68	63	km6.7
70	66	68	66	66	58	km7.7
71	64	70	64	66	58	km8.7
68	65	66	64	64	60	km9.7
65	67	67	64	68	60	gh1.7
65	68	67	67	69	63	gh2.7
65	68	67	66	68	63	gh3.7
65	66	68	63	68	62	gh4.7
66	68	66	66	68	62	gh5.7
66	67	66	67	70	64	gh6.7
64	64	66	63	66	59	gh7.7
64	66	65	64	66	60	gh8.7
65	66	65	64	65	62	gh9.7
66	65	65	65	67	64	gm1.7
67	64	67	65	65	61	gm2.7
66	65	67	65	67	62	gm3.7
65	67	67	65	67	65	gm4.7
63	66	64	66	64	63	gm5.7
65	67	66	64	63	60	gm6.7
66	67	67	67	67	63	gm7.7
65	67	67	67	67	58	gm8.7
64	67	65	64	64	61	gm9.7
64	62	63	64	66	57	ph1.8
65	62	62	64	62	54	ph2.8
65	64	61	62	66	64	ph3.8
65	63	61	64	66	56	ph4.8
66	62	62	63	65	60	ph5.8
65	64	62	65	66	63	ph6.8
62	61	62	63	66	56	ph7.8
64	62	61	63	64	54	ph8.8
65	60	62	62	65	64	ph9.8
70	59	63	63	70	62	pm1.8
69	61	65	64	68	60	pm2.8
70	61	65	64	70	60	pm3.8
68	61	62	65	71	63	pm4.8
65	63	62	62	63	58	pm5.8
66	62	60	62	66	61	pm6.8
65	60	61	63	65	56	pm7.8
66	62	62	64	65	62	pm8.8
65	64	62	63	65	60	pm9.8
62	62	62	63	65	53	bh1.8
60	62	60	63	65	64	bh2.8
58	63	60	63	66	66	bh3.8
61	61	63	64	65	66	bh4.8
60	62	63	63	66	58	bh5.8
60	62	62	64	64	64	bh6.8
60	62	62	62	65	61	bh7.8
62	60	62	64	67	63	bh8.8
61	62	63	64	65	51	bh9.8
58	58	60	61	68	62	bm1.8
59	61	63	61	66	63	bm2.8
59	62	60	63	65	63	bm3.8
59	60	60	62	68	59	bm4.8
58	62	59	62	64	62	bm5.8
57	61	57	63	62	63	bm6.8
59	63	57	63	60	65	bm7.8
61	62	60	63	69	64	bm8.8
61	62	60	63	66	62	bm9.8
66	63	61	64	64	66	th1.8
65	65	63	65	63	67	th2.8
64	65	61	65	63	68	th3.8
63	65	62	64	64	67	th4.8
65	65	63	64	64	67	th5.8
65	64	62	63	64	67	th6.8
64	64	62	65	64	66	th7.8
65	63	64	63	62	66	tm1.8
65	63	64	62	63	65	tm2.8
65	62	64	63	64	66	tm3.8
66	64	65	63	64	66	tm4.8
65	66	66	64	65	67	tm5.8
65	66	66	63	65	67	tm6.8
65	63	61	63	65	65	tm7.8
65	63	63	63	65	66	tm8.8
66	65	64	63	64	67	tm9.8
62	63	57	60	63	67	dh1.8
61	62	59	61	62	66	dh2.8
62	63	61	62	62	66	dh3.8
62	65	61	60	64	67	dh4.8
62	66	66	63	65	69	dh5.8
62	65	60	63	64	67	dh6.8
61	65	62	61	63	68	dh7.8
62	65	63	62	65	69	dh8.8
61	65	63	64	64	69	dh9.8
62	64	63	62	60	66	dm1.8
63	66	62	63	64	64	dm10.8
63	64	63	63	63	66	dm11.8
61	64	59	62	62	66	dm12.8
62	66	65	62	65	66	dm13.8
63	63	63	62	61	66	dm2.8
64	65	61	63	64	65	dm3.8
61	64	61	62	60	63	dm4.8
62	66	63	62	62	65	dm5.8
61	65	62	63	62	65	dm6.8
63	64	63	63	62	66	dm7.8
63	65	62	62	63	65	dm8.8
63	64	60	62	63	65	dm9.8
63	61	58	61	58	58	kh1.8
65	59	58	61	58	60	kh2.8
65	62	60	61	60	61	kh3.8
63	63	58	60	57	59	kh4.8
64	62	59	62	59	61	kh5.8
63	61	60	62	58	60	kh6.8
64	61	58	60	58	59	kh7.8
65	63	59	61	59	60	kh8.8
65	63	62	63	59	62	kh9.8

65	60	61	58	59	60	km1.8
65	63	59	62	61	59	km10.8
66	63	59	61	60	59	km11.8
66	59	63	60	59	59	km2.8
64	61	58	60	61	58	km3.8
63	59	58	58	59	60	km4.8
64	62	59	59	60	60	km5.8
65	62	58	61	58	58	km6.8
64	62	56	58	60	60	km7.8
63	62	59	60	59	61	km8.8
65	63	60	58	61	61	km9.8
62	62	63	57	59	61	gh1.8
61	62	59	60	60	63	gh2.8
59	60	59	62	59	61	gh3.8
61	61	61	63	61	63	gh4.8
61	63	59	62	63	65	gh5.8
62	64	58	61	61	61	gh6.8
62	64	57	61	60	63	gh7.8
62	64	62	63	61	64	gh8.8
61	65	60	61	60	65	gh9.8
63	62	60	63	58	62	gm1.8
63	63	57	62	58	60	gm2.8
62	64	60	62	57	61	gm3.8
62	62	58	61	57	56	gm4.8
61	63	58	58	58	57	gm5.8
60	65	61	64	57	60	gm6.8
63	63	59	63	59	62	gm7.8
62	64	60	64	61	61	gm8.8
61	62	60	62	59	58	gm9.8

Table 7.6. Numerical data for the fundamental frequency (Hz) at the onset (A), the middle (B), and the offset (C) of the vowel [a] following the class A and class B stops.

A	B	C	
157	153	152	ph1.1
160	154	152	ph2.1
171	155	154	ph3.1
179	159	150	ph4.1
165	159	161	ph5.1
179	157	150	ph6.1
171	154	152	ph7.1
167	150	150	ph8.1
168	153	147	ph9.1
157	125	118	pm1.1
156	137	126	pm10.1
154	131	124	pm11.1
132	126	119	pm12.1
147	123	118	pm2.1
137	127	122	pm3.1
152	129	119	pm4.1
142	124	117	pm5.1
129	117	109	pm6.1
136	126	125	pm7.1
146	125	119	pm8.1
131	126	118	pm9.1
165	145	167	bh1.1
171	131	165	bh2.1
169	130	150	bh3.1
140	133	146	bh4.1
118	129	157	bh5.1
156	126	152	bh6.1
150	134	146	bh7.1
129	128	153	bh8.1
118	135	153	bh9.1
146	125	120	bm1.1
129	123	118	bm2.1
152	124	120	bm3.1
143	122	117	bm4.1
135	123	118	bm5.1
134	122	118	bm6.1
135	126	120	bm7.1
134	123	120	bm8.1
140	123	116	bm9.1
159	159	152	th1.1
163	148	146	th2.1
159	149	145	th3.1
164	154	152	th4.1
172	154	150	th5.1
165	153	152	th6.1
182	159	154	th7.1
161	155	154	th8.1
174	163	153	th9.1
148	126	125	tm1.1
152	125	120	tm2.1
150	124	137	tm3.1
149	131	127	tm4.1
144	131	123	tm5.1
152	123	118	tm6.1
146	126	123	tm7.1
141	129	121	tm8.1
147	132	127	tm9.1
133	141	159	dh1.1
160	124	144	dh2.1
132	129	152	dh3.1
127	116	121	dh4.1
132	120	131	dh5.1
126	123	138	dh6.1
137	130	141	dh7.1
136	129	146	dh8.1
137	129	155	dh9.1
126	124	124	dm1.1
154	122	123	dm2.1
145	127	125	dm3.1
131	124	123	dm4.1
127	124	120	dm5.1
131	119	118	dm6.1
183	174	171	kh1.1
187	167	161	kh2.1
190	168	165	kh3.1
150	164	165	kh4.1
177	156	154	kh5.1
168	156	161	kh6.1
185	168	168	kh7.1
215	168	165	kh8.1
183	163	159	kh9.1
149	131	123	km1.1
167	130	126	km2.1
141	129	120	km3.1
168	140	132	km4.1
156	133	129	km5.1
164	130	124	km6.1
141	137	127	km7.1
153	140	129	km8.1
168	134	123	km9.1
146	135	168	gh1.1
263	123	148	gh2.1
153	132	152	gh3.1
142	137	165	gh4.1
147	133	157	gh5.1
150	131	159	gh6.1
131	139	167	gh7.1
150	135	169	gh8.1
180	132	165	gh9.1
141	130	126	gm1.1
163	126	123	gm2.1
135	120	117	gm3.1
142	129	126	gm4.1
165	121	117	gm5.1
123	118	118	gm6.1
153	126	124	gm7.1
165	122	118	gm8.1
172	120	118	gm9.1
267	244	215	ph1.2
260	230	206	ph2.2
267	235	230	ph3.2
274	244	202	ph4.2
278	235	202	ph5.2
263	227	208	ph6.2
263	208	175	ph7.2
260	244	225	ph8.2
260	238	215	ph9.2
270	217	204	pm1.2
263	213	220	pm2.2
263	213	192	pm3.2
244	215	190	pm4.2
260	204	180	pm5.2
250	211	200	pm6.2
263	217	180	pm7.2
241	202	215	pm8.2
244	211	187	pm9.2
202	238	256	bh1.2
213	244	260	bh2.2
241	241	256	bh3.2
227	244	270	bh4.2
227	247	263	bh5.2
233	247	270	bh6.2
227	244	244	bh7.2
211	263	303	bh8.2
238	247	282	bh9.2

227 206 220 bm1.2
225 208 222 bm2.2
213 211 215 bm3.2
222 202 190 bm4.2
206 192 192 bm5.2
200 202 194 bm6.2
215 213 202 bm7.2
213 196 213 bm8.2
215 200 211 bm9.2
290 256 241 th1.2
263 253 227 th2.2
299 256 238 th3.2
282 238 225 th4.2
270 244 227 th5.2
290 260 244 th6.2
290 247 247 th7.2
263 244 241 th8.2
282 260 233 th9.2
282 230 190 tm1.2
253 235 202 tm2.2
270 222 190 tm3.2
270 225 215 tm4.2
256 220 200 tm5.2
270 227 204 tm6.2
282 225 208 tm7.2
294 227 215 tm8.2
263 215 204 tm9.2
190 192 215 dh1.2
206 190 233 dh2.2
171 194 222 dh3.2
215 192 217 dh4.2
168 196 241 dh5.2
211 202 227 dh6.2
225 196 220 dh7.2
165 204 238 dh8.2
202 182 202 dh9.2
253 196 192 dm1.2
211 185 194 dm2.2
225 211 202 dm3.2
217 200 213 dm4.2
220 190 208 dm5.2
213 194 213 dm6.2
230 206 192 dm7.2
247 202 204 dm8.2
217 179 194 dm9.2
282 260 238 kh1.2
303 278 244 kh2.2
282 260 233 kh3.2
313 263 244 kh4.2
294 270 244 kh5.2
290 256 235 kh6.2
270 260 241 kh7.2
303 260 241 kh8.2
294 263 256 kh9.2
256 222 189 km1.2
274 233 198 km2.2
290 222 194 km3.2
294 227 200 km3.2
290 244 211 km4.2
278 230 196 km5.2
290 227 196 km6.2
282 230 202 km7.2
290 238 204 km8.2
282 227 206 km9.2
213 202 230 gh1.2
233 200 244 gh2.2
250 204 260 gh3.2
222 227 244 gh4.2
225 227 247 gh4.2
241 200 217 gh5.2
215 211 225 gh6.2
206 192 217 gh7.2
208 206 227 gh8.2
217 202 238 gh9.2
241 198 183 gm1.2
238 189 204 gm2.2
241 215 192 gm3.2
233 202 196 gm4.2
227 192 189 gm5.2
260 198 202 gm6.2
217 194 175 gm7.2
250 202 194 gm8.2
225 200 196 gm9.2
198 168 153 ph1.3
172 174 155 ph2.3
182 168 156 ph3.3
180 159 165 ph4.3
172 164 157 ph5.3
175 167 161 ph6.3
169 165 148 ph7.3
192 174 148 ph8.3
182 177 152 ph9.3
172 141 132 pm1.3
152 139 137 pm2.3
174 141 139 pm3.3
153 135 128 pm4.3
167 141 132 pm5.3
157 144 134 pm6.3
164 142 131 pm7.3
157 142 131 pm8.3
165 155 154 bh1.3
168 160 160 bh10.3
175 165 157 bh11.3
168 164 172 bh12.3
164 156 163 bh2.3
171 156 160 bh3.3
174 157 164 bh4.3
183 164 161 bh5.3
171 167 174 bh6.3
169 165 174 bh7.3
189 160 164 bh8.3
165 164 159 bh9.3
159 146 137 bm1.3
168 142 138 bm2.3
159 148 145 bm3.3
152 142 149 bm4.3
156 147 132 bm5.3
171 150 132 bm6.3
168 142 136 bm7.3
168 148 155 bm8.3
168 168 165 th1.3
190 180 171 th2.3
196 177 164 th3.3
200 172 163 th4.3
185 174 174 th5.3
183 174 175 th6.3
196 174 175 th7.3
185 174 169 th8.3
177 167 165 th9.3
171 152 153 tm1.3
174 152 155 tm10.3
171 152 171 tm11.3
175 155 144 tm12.3
175 153 142 tm2.3
171 150 144 tm3.3
174 157 152 tm4.3
168 156 154 tm5.3
161 149 141 tm6.3
168 150 140 tm7.3
183 156 164 tm8.3
175 159 145 tm9.3
183 165 160 dh1.3
185 165 167 dh2.3
172 165 171 dh3.3
159 161 157 dh4.3
171 165 175 dh5.3
175 165 172 dh6.3
159 160 163 dh7.3
164 163 159 dh8.3
182 157 165 dh9.3
157 147 140 dm1.3
163 150 146 dm2.3
157 149 146 dm3.3
161 146 139 dm4.3
177 150 140 dm5.3
152 149 145 dm6.3
154 146 137 dm7.3
161 147 140 dm8.3
165 147 145 dm9.3
192 167 164 kh1.3
174 172 164 kh2.3
182 169 157 kh3.3
172 163 153 kh4.3
182 165 157 kh5.3
172 159 156 kh6.3
171 161 152 kh7.3
194 164 152 kh8.3
183 161 165 kh9.3
160 147 144 km1.3
163 156 137 km2.3
185 148 139 km3.3
182 140 135 km4.3
167 147 139 km5.3
183 147 167 km6.3
172 153 147 km7.3
187 159 142 km8.3
190 147 142 km9.3
182 154 150 gh1.3
161 154 153 gh2.3
183 157 153 gh3.3
167 157 156 gh4.3
180 161 164 gh5.3
174 160 156 gh6.3
160 163 160 gh7.3
163 167 168 gh8.3
185 167 160 gh9.3
156 146 140 gm1.3
169 152 147 gm2.3
164 150 146 gm3.3
152 147 139 gm4.3
174 145 141 gm5.3
152 147 141 gm6.3
182 154 150 gm7.3
182 152 146 gm8.3
174 155 142 gm9.3
244 217 225 ph1.4

225 215 196 ph2.4
227 220 215 ph3.4
241 220 213 ph4.4
250 222 220 ph5.4
238 227 220 ph6.4
244 215 244 ph7.4
215 217 220 ph8.4
253 217 225 ph9.4
230 196 190 pm1.4
230 206 202 pm2.4
235 196 192 pm3.4
215 187 175 pm4.4
230 192 202 pm5.4
227 198 198 pm6.4
225 190 206 pm7.4
230 192 172 pm8.4
215 190 192 pm9.4
213 198 194 bh1.4
230 194 211 bh2.4
227 194 204 bh3.4
200 183 194 bh4.4
189 175 211 bh5.4
131 99 208 bh6.4
244 190 202 bh7.4
220 192 215 bh8.4
220 192 220 bh9.4
227 182 185 bm1.4
208 182 190 bm2.4
211 182 174 bm3.4
194 177 179 bm4.4
227 175 171 bm5.4
225 172 185 bm6.4
185 175 189 bm7.4
200 182 189 bm8.4
202 183 183 bm9.4
250 217 215 th1.4
256 220 217 th2.4
250 217 215 th3.4
250 222 215 th4.4
244 215 206 th5.4
244 227 220 th6.4
227 215 220 th7.4
244 220 222 th8.4
250 222 220 th9.4
238 204 196 tm1.4
247 204 198 tm2.4
227 196 192 tm3.4
233 192 194 tm4.4
244 208 200 tm5.4
244 196 200 tm6.4
235 196 192 tm7.4
241 202 196 tm8.4
244 204 194 tm9.4
213 194 202 dh1.4
241 189 194 dh2.4
227 192 213 dh3.4
206 194 204 dh4.4
204 194 206 dh5.4
213 190 202 dh6.4
187 182 196 dh7.4
220 190 198 dh8.4
222 189 196 dh9.4
196 185 182 dm1.4
204 194 190 dm2.4
253 185 183 dm3.4
194 185 187 dm4.4
220 183 185 dm5.4
227 182 177 dm6.4
163 169 174 dm7.4
200 177 183 dm8.4
198 180 175 dm9.4
260 217 213 kh1.4
253 217 225 kh2.4
235 215 206 kh3.4
247 220 220 kh4.4
244 213 213 kh5.4
238 215 204 kh6.4
241 225 213 kh7.4
247 217 211 kh8.4
233 215 220 kh9.4
241 200 189 km1.4
250 202 194 km2.4
244 202 192 km3.4
230 200 190 km4.4
244 200 189 km5.4
250 196 192 km6.4
235 200 190 km7.4
233 204 196 km8.4
227 194 190 km9.4
233 196 194 gh1.4
217 202 200 gh10.4
211 189 194 gh11.4
213 190 196 gh12.4
220 204 196 gh2.4
206 190 192 gh3.4
215 202 206 gh4.4
192 187 190 gh5.4
217 189 198 gh6.4
206 185 190 gh7.4
220 198 200 gh8.4
211 192 194 gh9.4
244 190 182 gm1.4
206 187 183 gm2.4
225 192 185 gm3.4
215 185 192 gm4.4
225 185 202 gm5.4
227 183 194 gm6.4
215 185 182 gm7.4
227 179 182 gm8.4
220 185 182 gm9.4
238 213 213 ph1.5
247 206 213 ph2.5
244 211 211 ph3.5
235 202 194 ph4.5
230 211 215 ph6.5
233 204 204 ph7.5
241 202 215 ph8.5
235 202 194 ph9.5
225 185 190 pm1.5
230 192 182 pm2.5
244 189 189 pm3.5
225 192 183 pm4.5
247 196 192 pm5.5
225 189 192 pm6.5
233 187 189 pm7.5
225 189 182 pm8.5
227 190 180 pm9.5
202 182 185 bh1.5
174 183 211 bh2.5
160 185 211 bh3.5
202 196 204 bh4.5
185 190 213 bh5.5
172 189 192 bh6.5
192 192 185 bh7.5
177 194 204 bh8.5
202 196 200 bh9.5
177 175 172 bm1.5
185 185 167 bm2.5
187 182 171 bm3.5
196 192 174 bm4.5
182 183 182 bm5.5
174 183 171 bm6.5
196 185 174 bm7.5
211 183 174 bm8.5
187 182 190 bm9.5
225 192 179 th1.5
256 200 172 th2.5
238 202 175 th3.5
227 196 194 th4.5
250 190 172 th5.5
225 194 174 th6.5
270 187 169 th7.5
217 192 179 th8.5
220 190 187 th9.5
260 165 177 tm1.5
215 185 164 tm10.5
206 174 165 tm2.5
220 174 152 tm3.5
244 190 171 tm4.5
213 174 150 tm5.5
233 175 163 tm6.5
220 190 156 tm7.5
233 192 168 tm8.5
220 187 172 tm9.5
211 183 182 dh1.5
260 185 183 dh10.5
196 190 185 dh11.5
192 192 180 dh12.5
182 192 208 dh2.5
189 189 182 dh3.5
208 183 175 dh4.5
215 189 192 dh5.5
192 192 196 dh6.5
215 190 182 dh7.5
211 192 185 dh8.5
190 183 187 dh9.5
215 183 174 dm1.5
233 172 147 dm2.5
200 169 165 dm3.5
233 189 171 dm4.5
213 182 154 dm5.5
215 183 155 dm6.5
202 180 153 dm7.5
213 168 150 dm8.5
233 180 161 dm9.5
238 202 192 kh1.5
256 206 202 kh10.5
241 196 200 kh11.5
260 211 217 kh12.5
247 215 211 kh2.5
227 215 217 kh3.5
227 204 206 kh4.5
233 202 206 kh5.5
260 211 200 kh6.5
222 211 200 kh7.5
256 204 192 kh8.5

227	198	225	kh9.5
230	185	171	km1.5
238	182	174	km2.5
235	185	182	km3.5
227	196	182	km4.5
238	185	174	km5.5
282	187	165	km6.5
290	185	182	km7.5
238	187	185	km8.5
217	185	182	km9.5
233	189	202	gh1.5
194	171	185	gh10.5
171	190	183	gh11.5
187	190	194	gh12.5
222	180	179	gh2.5
175	180	200	gh3.5
198	194	211	gh4.5
202	190	196	gh5.5
217	190	192	gh6.5
233	192	196	gh7.5
183	190	187	gh8.5
238	189	192	gh9.5
200	179	165	gm1.5
185	177	171	gm2.5
220	182	175	gm3.5
220	180	164	gm4.5
215	180	165	gm5.5
182	175	164	gm6.5
215	180	169	gm7.5
206	180	168	gm8.5
238	182	174	gm9.5
174	164	153	ph1.6
174	165	152	ph2.6
185	159	159	ph4.6
182	159	153	ph5.6
183	164	160	ph6.6
182	161	160	ph7.6
179	164	159	ph8.6
194	167	150	ph9.6
153	131	136	pm1.6
159	125	136	pm3.6
165	136	140	pm4.6
147	131	118	pm5.6
157	130	124	pm6.6
163	135	135	pm7.6
164	135	129	pm8.6
161	139	127	pm9.6
123	137	147	bh1.6
147	143	153	bh2.6
146	133	156	bh3.6
192	154	161	bh4.6
126	132	155	bh5.6
154	137	154	bh6.6
134	145	159	bh7.6
118	138	152	bh8.6
121	145	156	bh9.6
152	124	127	bm1.6
154	128	120	bm2.6
163	123	131	bm3.6
130	130	121	bm4.6
137	126	117	bm5.6
134	125	135	bm6.6
140	129	139	bm7.6
148	127	104	bm8.6
143	123	135	bm9.6
185	164	150	th1.6
174	165	148	th2.6
189	165	165	th3.6
189	167	146	th4.6
164	163	148	th5.6
168	165	159	th6.6
196	157	154	th7.6
174	156	148	th8.6
182	164	149	th9.6
164	130	136	tm1.6
149	129	124	tm2.6
135	124	118	tm3.6
159	126	123	tm4.6
154	126	140	tm5.6
138	126	134	tm6.6
153	129	135	tm7.6
159	129	125	tm8.6
153	130	122	tm9.6
133	121	148	dh1.6
139	123	134	dh2.6
135	122	123	dh3.6
140	126	131	dh4.6
126	123	132	dh5.6
137	132	133	dh6.6
146	125	141	dh7.6
138	130	132	dh8.6
137	132	133	dh9.6
146	118	107	dm1.6
137	118	131	dm2.6
134	117	111	dm3.6
146	118	109	dm4.6
140	119	121	dm5.6
135	113	107	dm6.6
137	116	110	dm7.6
139	116	110	dm8.6
137	119	120	dm9.6
165	159	154	kh1.6
169	160	153	kh2.6
174	152	141	kh3.6
174	159	157	kh4.6
167	159	157	kh5.6
164	159	155	kh6.6
185	165	152	kh7.6
171	165	154	kh8.6
171	167	159	kh9.6
156	126	132	km1.6
143	125	117	km2.6
135	127	119	km3.6
156	125	114	km4.6
135	123	119	km5.6
148	126	120	km6.6
139	133	123	km7.6
150	134	126	km8.6
145	134	129	km9.6
132	127	135	gh1.6
137	120	118	gh2.6
133	120	115	gh3.6
126	115	110	gh4.6
126	117	117	gh5.6
132	118	109	gh6.6
138	116	105	gh7.6
137	115	112	gh8.6
114	115	108	gh9.6
131	119	118	gm1.6
127	118	116	gm2.6
128	118	110	gm3.6
133	118	116	gm4.6
137	115	110	gm5.6
133	118	112	gm6.6
152	116	109	gm7.6
147	118	113	gm8.6
129	115	113	gm9.6
282	267	241	ph1.7
299	270	225	ph2.7
299	267	238	ph3.7
282	260	244	ph4.7
270	250	233	ph5.7
274	260	253	ph6.7
263	250	247	ph7.7
260	247	250	ph8.7
250	235	244	ph9.7
253	244	217	pm1.7
267	230	211	pm2.7
290	230	206	pm3.7
260	225	208	pm4.7
274	235	196	pm5.7
274	230	211	pm6.7
247	227	204	pm7.7
244	217	211	pm8.7
270	241	215	pm9.7
263	256	238	bh1.7
227	230	238	bh10.7
263	241	235	bh11.7
233	244	227	bh12.7
220	244	238	bh2.7
222	247	244	bh3.7
217	241	225	bh4.7
222	241	244	bh5.7
211	244	244	bh6.7
263	244	250	bh7.7
227	244	244	bh8.7
270	244	244	bh9.7
227	222	202	bm1.7
227	222	192	bm10.7
211	227	202	bm11.7
256	225	220	bm12.7
238	241	211	bm2.7
211	227	213	bm3.7
241	230	204	bm4.7
233	217	213	bm5.7
303	220	213	bm6.7
220	235	230	bm7.7
230	233	222	bm8.7
294	206	213	bm9.7
282	256	233	th1.7
282	241	227	th10.7
278	233	222	th11.7
256	241	230	th12.7
270	250	241	th2.7
282	244	213	th3.7
282	241	217	th4.7
290	241	215	th5.7
260	230	217	th6.7
267	241	215	th7.7
274	238	220	th8.7
278	233	227	th9.7
267	227	213	tm1.7
282	233	220	tm2.7
274	244	215	tm3.7
290	238	217	tm4.7
282	230	202	tm5.7

303	238	215	tm6.7
282	220	213	tm7.7
282	222	208	tm8.7
278	227	202	tm9.7
241	225	217	dh1.7
247	227	227	dh10.7
282	247	230	dh2.7
227	222	217	dh3.7
230	220	230	dh4.7
215	220	225	dh5.7
215	227	227	dh6.7
208	225	222	dh7.7
244	222	225	dh8.7
230	222	227	dh9.7
250	211	198	dm1.7
217	206	190	dm2.7
270	204	196	dm3.7
233	204	192	dm4.7
225	204	192	dm5.7
235	204	194	dm6.7
233	208	192	dm7.7
278	204	194	dm8.7
227	204	202	dm9.7
256	238	227	kh1.7
278	241	225	kh2.7
270	238	220	kh3.7
282	241	230	kh4.7
286	247	233	kh5.7
260	235	227	kh6.7
278	244	217	kh7.7
278	241	227	kh8.7
263	233	225	kh9.7
267	238	217	km1.7
260	225	213	km10.7
270	215	202	km11.7
270	225	211	km12.7
263	230	215	km2.7
282	227	227	km3.7
278	230	208	km4.7
278	230	211	km5.7
267	230	202	km6.7
250	215	204	km7.7
260	215	215	km8.7
260	215	202	km9.7
253	220	220	gh1.7
260	217	217	gh2.7
263	225	230	gh3.7
263	225	220	gh4.7
260	213	227	gh5.7
256	215	222	gh6.7
250	222	235	gh7.7
247	217	227	gh8.7
263	220	215	gh9.7
247	200	194	gm1.7
235	200	196	gm2.7
282	208	200	gm3.7
263	220	206	gm4.7
256	215	200	gm5.7
270	204	196	gm6.7
270	213	202	gm7.7
250	213	202	gm8.7
278	202	211	gm9.7
190	189	183	ph1.8
196	190	183	ph2.8
187	182	163	ph3.8
182	180	183	ph4.8
202	185	164	ph5.8
190	180	185	ph6.8
204	189	190	ph7.8
202	190	185	ph8.8
185	187	175	ph9.8
168	149	157	pm1.8
167	148	141	pm2.8
172	152	139	pm3.8
118	156	147	pm4.8
165	152	132	pm5.8
182	144	157	pm6.8
183	159	155	pm7.8
175	155	153	pm8.8
182	159	159	pm9.8
146	155	167	bh1.8
146	150	179	bh2.8
150	145	165	bh3.8
157	159	180	bh4.8
154	153	175	bh5.8
160	159	185	bh6.8
146	148	189	bh7.8
156	160	182	bh8.8
153	161	172	bh9.8
156	142	131	bm1.8
164	148	146	bm2.8
156	143	140	bm3.8
152	141	146	bm4.8
155	140	139	bm5.8
156	135	143	bm6.8
152	139	130	bm7.8
163	141	131	bm8.8
159	143	137	bm9.8
196	182	182	th1.8
194	180	165	th2.8
206	177	189	th3.8
190	183	171	th4.8
189	175	175	th5.8
211	179	183	th6.8
211	180	182	th7.8
196	157	153	tm1.8
172	159	171	tm2.8
196	159	152	tm3.8
200	160	164	tm4.8
211	161	153	tm5.8
192	164	156	tm6.8
185	161	155	tm7.8
185	163	172	tm8.8
192	165	157	tm9.8
145	140	165	dh1.8
144	136	157	dh2.8
152	137	177	dh3.8
155	150	182	dh4.8
155	148	183	dh5.8
148	140	163	dh6.8
154	157	175	dh7.8
149	147	192	dh8.8
156	159	175	dh9.8
150	132	130	dm1.8
159	139	159	dm10.8
185	139	129	dm11.8
152	138	143	dm12.8
164	142	156	dm13.8
147	132	126	dm2.8
154	142	155	dm3.8
152	128	139	dm4.8
165	132	140	dm5.8
150	132	95	dm6.8
157	137	135	dm7.8
159	136	126	dm8.8
156	137	168	dm9.8
185	171	145	kh1.8
168	167	153	kh2.8
174	165	136	kh3.8
177	168	153	kh4.8
172	159	154	kh5.8
175	161	150	kh6.8
157	169	141	kh7.8
220	167	146	kh8.8
177	161	144	kh9.8
177	150	141	km1.8
175	154	132	km10.8
177	150	130	km11.8
156	150	135	km2.8
183	154	133	km3.8
187	148	141	km4.8
200	147	132	km5.8
157	148	127	km6.8
172	149	140	km7.8
174	140	133	km8.8
175	145	125	km9.8
150	148	148	gh1.8
157	146	146	gh2.8
140	135	137	gh3.8
152	141	154	gh4.8
165	156	159	gh5.8
159	142	152	gh6.8
167	146	156	gh7.8
168	152	153	gh8.8
182	152	160	gh9.8
164	133	115	gm1.8
155	130	120	gm2.8
180	136	114	gm3.8
149	129	118	gm4.8
154	140	120	gm5.8
164	134	120	gm6.8
157	139	123	gm7.8
171	141	124	gm8.8
169	136	127	gm9.8

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