ACOUSTIC CONDITIONING FOR THE RUKI RULE

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by

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Abstract

The RUKI rule describes the diachronic shift in the satem group of Indo-European languages in which Proto-Indo-European (PIE) */s/ following */r, u, k and i/ became /ʃ/ in Baltic and Iranian , /x/ in Slavic and retroflex /ṣ/ in Old Indic. This thesis presents experimental data to support the hypothesis that the RUKI rule was acoustically conditioned.

The main data collection for this study was carried out using a series of RUKI and non-RUKI pairs. Informants were asked to read a list of words which contained /s/ in RUKI and non-RUKI environments. Spectrographic data from informants was collected and displayed on a Macintosh Computer using the Signalyze Speech Analysis program. Spectrograms of the isolated fricatives, /f/, /s/, /ʃ/, /ṣ/, /ç/, /x/ and of /isa/, /asa/, /usa/ and /iʃa/, /aʃa/, /uʃa/ were also obtained. The fricative noise portions of all spectrograms were assessed for the presence or absence of an initial frequency component below 3500 Hz. In addition, each RUKI/non-RUKI pair was compared to determine if the RUKI member of each pair had: 1) an initial concentration of fricative noise energy below a frequency of 3500 Hz compared to none for the non-RUKI pair; 2) a lower continuous concentration of noise energy and; 3) greater overall intensity of the fricative noise spectra.

The acoustic data presented here demonstrate that the elements conditioning the RUKI shift form an acoustic natural class which lowers the noise frequency of a following /s/. The resulting fricative sound is acoustically similar to post-alveolar fricatives, in particular, palato-alveolar /ʃ/. Analysis of the relative strengths of the acoustic conditioning of the four RUKI elements shows /r/ as the strongest and /u/ the weakest.

This acoustic evidence supports the arguments that the diachronic development of the RUKI shift was a common innovation within the satem group of languages and that the RUKI shift was initially to palato-alveolar /ʃ/ with secondary changes to /x/ in Slavic and /ṣ/ in Old Indic. Using a wave model, the relative acoustic strengths of the RUKI conditioning elements are used to describe the propagation of dialects within the satem group of languages.

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Table of Contents

Page

Abstract ... ii

Acknowledgements ... iv

List of Tables ... vii

List of Figures ... viii

Abbreviations ... ix

1.0 Introduction ... 1
- 1.1 Hypothesis ... 1
- 1.2 Objectives ... 2
- 1.3 Phonological Assumptions and Notation ... 2
- 1.4 Historical Context of the RUKI Change ... 4
- 1.5 RUKI as a Satem Language Innovation ... 9
- 1.6 Synchronic Versus Diachronic Change ... 11
- 1.7 Conditioning Factors ... 12

2.0 Methods ... 15
- 2.1 Preliminary Study ... 15
- 2.2 Main Study ... 16
  - 2.2.1 Information Recorded ... 16
  - 2.2.2 Informants ... 17
  - 2.2.3 Instrumentation ... 18
  - 2.2.4 Analysis ... 19

3.0 Results ... 20
- 3.1 Isolated Fricatives ... 20
- 3.2 Comparison of /s/ and /ʃ/ ... 21
- 3.3 Acoustic Characteristics of s in RUKI Environment ... 22
  - 3.3.1 Following /r/ ... 22
  - 3.3.2 Following /k/ ... 23
  - 3.3.3 Following /i/ ... 23
  - 3.3.4 Following /u/ ... 24
  - 3.3.5 RUKI Versus Non-RUKI Environments ... 25

List of Tables

Page

Table 1: Orthographic Representation of Sibilants 2

Table 2: Phonemic Inventory of PIE Consonant System 3

Table 3: Phonemic Inventory of PIE Vowel System 4

Table 4: Some Reflexes of PIE */s/ Following */r/ 4

Table 5:Some Reflexes of PIE */s/ Following */u/ 5

Table 6: Some Reflexes of PIE */s/ Following */k/ 5

Table 7: Some Reflexes of PIE */s/ Following */i/ 5

Table 8: Old Church Slavic Reflexes with /x/ and /ʃ/ 6

Table 9: RUKI Environment Before Voiceless Obstruents 7

Table 10: Baltic and Slavic Consonant Simplification 7

Table 11: Some Baltic Irregularities after */i/ 8

Table 12: Some Balto-Slavic Irregularities following */u/ 8

Table 13: Information Recorded 16

Table 14: RUKI and Non-RUKI Pairs in Word List 17

Table 15: Acoustic Affinity Between Velars and Labials 35

Table 16: Palatalized Labials and Dentals in Czech Têtak Dialect 35

Table 17: Assibilation and RUKI 36

Table 18: Assibilation of PIE */k^y/ in Nuristani compared to Sanskrit 37

Table 19: Output of */k^y/ Assibilation in Strong Conditioning Environment 38

Table 20: Propagation of Temporal Dialects
through Social and Geographical Space 44

Table 21: Nuristani reflexes of PIE */s/ in RUKI environment 47

List of Figures

Page

Figure1: Initial Fricative Frequency < 3500 Hz for RUKI
and Non-RUKI Environments 26

Figure 2: Spectral Characteristics of /s/ in RUKI
Compared to Non-RUKI Environments 26

Figure 3: Isolated Fricatives, Spectrogram 58

Figure 4: Isolated Fricatives, Spectra and RMS Envelope 59

Figure 5: RUKI Vowel Environment for /s/ and /ʃ/ 60

Figure 6: /rs/ Environment Compared to /ls/ 61

Figure 7: /rs/ Environment Compared to /ls/ 62

Figure 8: /rs/ Environment Compared to /ls/ 63

Figure 9: Illustration of /rs/ for Tongue Body /r/ 64

Figure 10: Illustration of /rs/ for Retroflex /r/ 65

Figure 11: Illustration of /rs/ Trilled /r/ for Czech Speaker 66

Figure 12: Illustration of /rs/ Trilled /r/ for Russian Speaker 67

Figure 13: Example of /ks/ Compared to /ts/ and /ps/ 68

Figure 14: Example of /ks/ Compared to /ts/ and /ps/ 69

Figure 15: Example of /ks/ Compared to /ts/ and /ps/ 70

Figure 16: Example of /is/ Compared to /us/ and /ʌs/ 71

Figure 17: Example of /is/ Compared to /us/ and /ɑs/ 72

Figure 18: Example of /is/ Compared to /us/ and /ʌs/ 73

Figure 19: Illustration of Vowel Related Transitions for /is/ and /us/ 74

Figure 20: Illustration of Fricative Noise Pattern after /ks/
Spectrogram and Spectral Sections 75

Figure 21: Example of 'dropped' British /r/ 76

Abbreviations Used

Languages

Bul	Bulgarian
Grk	Greek
Goth	Gothic
Latv	Latvian
Lith	Lithuanian
Per	Persian
PIE	Proto-Indo-European
Mac	Macedonian
MHG	Middle High German
ModE	Modern English
OCS	Old Church Slavic
OCz	Old Czech
OE	Old English
OHG	Old High German
OLat	Old Latin
ON	Old Norse
OPer	Old Persian

Grammatical

LOC	Locative case

1.0 INTRODUCTION

"History is the version of past events that people have decided to agree upon." ------ Napoleon Bonaparte (1769-1821)

1.1 HYPOTHESIS

The Balto-Slavic and Indo-Iranian groups of Indo-European languages share several common characteristics not found in other Indo-European languages. Both are members of the so-called 'satem' group of languages in which Proto-Indo-European (PIE) palatalized */k/ became a sibilant. Both groups also share a shift of PIE */s/ to post-alveolar fricatives, but only in certain specific environments: when PIE */s/ followed the liquid */r/, the high back vowel */u/, the voiceless velar stop */k/, or the high front vowel */i/. This shift is called the RUKI Rule. The RUKI rule was first stated by Holger Pedersen (1895) to describe the shift in the Balto-Slavic languages in which PIE */s/ became /ʃ/ in Baltic and /x/ in Slavic. In Indo-Iranian, this historical shift resulted in an /ʃ/ in Iranian and retroflex /ṣ/ in Old Indic.

It has been difficult for historical linguists to explain this RUKI shift in terms of a natural class for the conditioning elements *r, *u,*k and *i. It is particularly difficult to postulate a common place or nature of articulation for these four phonemes. Vennemann, in 1974, suggested an alternative; that the explanation is a matter of acoustics and that RUKI forms a "relative acoustic natural class" which lowers the frequencies of the energy concentration in a following /s/ (Vennemann 1974:95). It is this hypothesis that I have chosen to investigate.

1.2 OBJECTIVES

My objectives are:

1. To describe the diachronic development of the RUKI shift in the Indo-Iranian and Balto-Slavic languages.

2. To examine the conditioning factors producing this shift.

3. To provide an acoustic explanation for the RUKI change by:

   a. Comparing the spectrographic data for /s/ following /r/, /u/, /k/ and /i/ to that of /s/ in a non-RUKI environment

   b. Comparing the spectrographic data for /s/ in both environments to that of /ʃ/, /x/ and retroflex /ṣ/.

1.3 PHONOLOGICAL ASSUMPTIONS AND NOTATION

For the various languages I will be citing here, many different orthographic representations of the sibilants are used, particularly for the palato-alveolar sibilant. For purposes of consistency, sibilants in words in all languages are presented in this thesis using the following forms:

Table 1: Orthographic Representation of Sibilants

My notation	Place of Articulation
s	dental or alveolar
ṣ	retroflex
ʃ	palato-alveolar

I will use standard phonological notation with slanted brackets, /ʃ/ , for phonemic representation and square brackets, [ʃ], denoting phonetic. All reconstructed forms will be noted with an asterisk. Cited forms will be transliterated where necessary. Some cited forms are transliterated to give a more phonetic presentation and to illustrate more clearly the RUKI environment in question e.g. Latin *texō* 'weave' is shown as *te[ks]ō*. Word glosses will be enclosed in single quotes.

I will assume a phonemic inventory for PIE following Szemerényi 1996 [1990]:37 as shown in Table 2 and 3; and all reconstructed Proto-Indo-European words will be presented using the orthographic characters in these tables. PIE reconstructed forms are taken primarily from Stuart Mann 1984 with confirmation wherever possible from Walde & Pokorny I & II, 1927-32 or Pokorny 1959-69. Some Sanskrit reflexes were taken from Monier-Williams 1993 and Goldman and Sutherland 1987.

Table 2: Phonemic Inventory of PIE Consonant System

Szemerényi 1996 [1990]

	Labial	Alveolar	Palatal	Velar	Labial-velars
Stops	p b	t d	k^y g^y	k g	k^w g^w
	ph bh	th dh	kh^y gh^y	kh gh	kh^w gh^w
Fricatives		s			
Nasals	m	n			
Liquids/Glides		l r	y		w

Table 3: Phonemic Inventory of PIE Vowel System from Szemerényi 1996 [1990]				
i i:				u u:
	e e:	ə	o o:	
		a a:		

1.4 HISTORICAL CONTEXT OF THE RUKI CHANGE

The RUKI rule was first stated by Holger Pedersen (1895) to describe the shift in the Balto-Slavic languages in which PIE */s/ became /ʃ/ in Baltic (examples here in Lithuanian, Latvian) and /x/ in Slavic (examples here in Old Church Slavic, Old Czech). In Indo-Iranian, this historical shift resulted in an /ʃ/ in Iranian (examples here in Avestan, Old Persian) and retroflex /ṣ/ in Old Indic (examples here in Sanskrit). In contrast, Indo-European "centum" languages such as Latin, retain the original PIE /s/.

Table 4: Some Reflexes of PIE */s/ following */r/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*tr̥stos 'dry'	tr̥ṣṭaḥ 'dry'	reʃt 'arid'	tirʃtas 'stiff'		tostus 'parched'
*wr̥s- 'top,protrusion'	varṣman 'top, height'		virʃus 'over, above'	vrŭxŭ 'over, above'	verrūca 'wart'
*pr̥s(k) 'spurt,sprinkle'	pr̥ṣat- 'speckled, spotted'	parəʃ 'drip'	purʃkiu 'drizzle'	prʃeti 'rain'	**ON** fors 'waterfall'

Table 5: Some Reflexes of PIE */s/ following */u/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*yeus, yu:s 'mix, broth'	yūṣ 'soup'		juʃe 'fish soup'	juxa	ius, jus
*wetus 'old, age'			vetuʃ-as	vetŭxŭ	vetus 'old'
*(a)us- 'dawn'	uṣas	uʃa	auʃra		**MHG** o:st

Table 6: Some Reflexes of PIE */s/ following */k/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*loksos 'crooked'	rākṣasa 'demon' ṛkṣa 'evil,bear'		lokys 'evil' urkʃti 'grunt'	loʃi 'bad, evil'	**OLat** ur[ks]us 'bear'
*auks, augs- 'high,grow'	ukṣati 'wet,sprinkle'	ukʃyati 'increase,grow'	aukʃtas 'high'		augustus 'high'
*ruksios 'harsh'	rukṣaḥ 'rough'		rukʃtus 'harsh, sour'	ot-ruxolŭ 'dishelved'	

Table 7: Some Reflexes of PIE /s/ following /i/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Greek**
*trisios 'threefold, thrice'	triṣu three (LOC)		trise	trixŭ LOC	trissos
*isios 'arrow, dart'	iṣuḥ 'arrow'	iṣus "arrow'			īos 'javelin'
*stisthāmi 'I stand'	tiṣṭhāmi	histmāmi			**Latin** sistō
*mois, moisks 'skin bag'	meṣaḥ 'ram,fleece'	maeʃo 'sheep'	maiʃas 'bag'	mexŭ 'skin'	**OHG** meise 'basket'

Within the Indo-Iranian and Balto-Slavic language groups, the generality and regularity of the RUKI changes are not evenly distributed. Indo-Iranian shows the changes in their most complete and regular form after PIE */r/, */u/, */k/ and */i/ (Hock 1991:443). The vowels conditioning this shift in Old Indic include /e:/ and /o:/ which are reflexes of Proto-Indic diphthongs */ai/ and */au/.

Slavic and Baltic exhibit the changes in some forms, while others show unshifted segments (Hock 1991:443, Andersen 1968, Pedersen 1895). The RUKI shift of PIE */s/ in Old Church Slavic may also be conditioned by a following segment, with a shift to /x/ before non-front vowels /o/, /u/ and /a/ but to /ʃ/ before front vowels /i/ and /e/ (Allen 1973).

Table 8: Old Church Slavic Reflexes with /x/ and /ʃ/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*m(o)us-, moksa 'fly, gnat'	maksa 'fly'	muso 'fly'	musse 'fly'	muxo 'fly'	musca 'fly'
*wṛs- 'top, protrusion'	varsman 'top, height'		virʃus 'top'	vrŭxsŭ 'top'	verrūca 'wart'
*yeu-s, yu:s 'mix'	yūs 'soup'		juʃe 'fish soup'	juxa 'soup'	ius, jus 'juice'
*loksos 'crooked'	rāksasa 'demon' ṛksa 'evil,bear'		lokys 'bear'	loʃi 'bad, evil'	ursus 'bear'
			ʃirʃuo 'hornet'	srŭʃent 'hornet'	
*mu:s 'mouse, muscle'	mus 'mouse'	**OPer** muʃ 'mouse'		myʃica 'muscle'	mūs 'mouse' musculus 'muscle'

In addition, in Old Church Slavic, RUKI appears to be blocked from applying before a voiceless obstruent. (Hock 1991:443, Pedersen 1895).

Table 9: RUKI environment before voiceless obstruents					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*pr̥sto- , pr̥sthis 'sticking out'	pr̥ṣṭha 'back'	parʃta- 'backbone'	priʃtas 'finger'	prŭstŭ 'finger'	postis 'post'
*ais-sk 'wish, desire'	icchati 'want, seek'	iʃ- 'want, seek'	ieʃkoti 'seek'	iskati 'seek'	**ModE** ask
*list- 'guile'			**Latv** liʃkis 'flatterer'	listi 'cunning, deceit'	**OE** list 'guile, cunning

Both Baltic and Slavic consistently show a RUKI shift after PIE */r/ and with few exceptions also after PIE */k/, although the /k/ often disappears due to consonant cluster simplification.

Table 10: Baltic and Slavic Consonant Simplification							
***PIE**	**Sanskrit**	**Per**	**Lith**	**Latv**	**OCS**	**Grk**	**Latin**
*teks 'shape, carve'	takṣāmi 'shape' takṣan 'carpenter'	takste 'board'	taʃaũ 'hew, shape'	teʃu 'hew, shape'	teʃɔ 'hew, shape'	tektōn 'carpenter'	te[ks]ō 'weave'
*wiks 'twig'			vikʃris 'bundle bunch'	vikʃis 'bundle'	viʃi 'green bough'		viscus 'mistletoe'

There is less regularity in the Balto-Slavic language groups after */i/ and */u/ (Pedersen 1895, Andersen 1968). Whereas Old Church Slavic shows consistent change after PIE */i/, Lithuanian and Latvian exhibit some segments shifted to */ʃ/ and others unchanged after PIE */i/.

Table 11: Some Baltic Irregularities after */i/					
***PIE**	**Sanskrit**	**Avestan**	**Lith**	**OCS**	**Latin**
*trisios 'threefold'	triṣu		trise	trixŭ	trīnus
*mois, moisks 'skin bag'	meṣaḥ 'ram,fleece'	maeʃo 'sheep'	maiʃas 'bag'	mexŭ 'skin'	**ON** meise 'basket'
*reisō 'snatch'	reṣyāmi 'injure'	raeʃ 'wound'	rieʃu 'split, burst'		**OE** rīsan 'seize'
*oisos 'passion, craving'	eṣa 'craving, wish'	aeʃo 'desirous, gay'	aisus 'moody'		**MHG** (fr)-eise 'horrible'
*kisik- 'shank, forearm'	kiṣkuḥ 'forearm, axehandle'		kiʃka 'hock, bend of knee'	**Latv** ciska 'hip, haunch'	

Both Baltic and Slavic reflexes of PIE */s/ following */u/ show some shifted and some unchanged segments.

Table 12: Some Balto-Slavic Irregularities following */u/					
***PIE**	**Sanskrit**	**Lith**	**Latv**	**OCS**	**Latin**
*m(o)usiə 'fly,gnat'	makṣā 'fly'	musse 'fly'		muxa 'fly'	musca 'fly'
*kusi 'tug, drag, incite'	kuṣāmi 'force, draw out'	kuʃu 'stir,move'	kusls 'ailing'	kusinu 'sluggish'	
*trus- 'shrubbery'			truʃi 'reeds'	trŭsŭ 'vine'	
*rus 'red'	ruṣyāmi 'am angry'		rusa 'glow'	**OCz** rusjo 'fox-red'	russus 'red'

There are two distinct questions regarding the RUKI rule which have been discussed in the literature over the years: first is the question of whether the development in Balto-Slavic and Indo-Iranian can be considered together as a unique innovation within the satem family and secondly is the question of whether the sound change following /r/, /u/, /k/ and /i/ can actually be considered as a single rule.

1.5 RUKI AS A SATEM LANGUAGE INNOVATION

There has been much discussion in the literature on the order of the RUKI changes in these languages and their relationship to one another. Masica (1991:33) believes that PIE */s/ became */ṣ/ and then later changed to /ʃ / in Iranian and /x/ in Slavic. Uhlenbeck (1977:103) states that the change was from */s/ to /ʃ/ during the early Indo-Iranian period and that /ʃ/ was later "lingualized" in the Indian languages leading to Sanskrit /ṣ/ but remained /ʃ/ in Iranian. Both Uhlenbeck (Meillet 1967:110) and Martinet (1951) have expressed doubts about the connection between the Indo-Iranian changes and the Balto-Slavic changes. However, Hock (1991:442) concludes that the RUKI changes can "only be attributed to a common innovation" within the satem group of languages since the RUKI changes are neither very common nor easily explainable (in terms of articulatory assimilation). This opinion is shared by Masica (1991:33), Burrow (1976:37) and Meillet (967:110).

If the RUKI sound change was an evolution of the satem group as a whole, attention must be given to the order of the changes within the various satem dialects. I suggest that the initial sound shift was */s/ > */ʃ/ in the satem language group at a stage before Proto-Balto-Slavic and Proto-Indo-Iranian became distinct. The two branches then took separate courses, which led to /x/ in Slavic, /ṣ/ in Sanskrit, with /ʃ/ remaining in Baltic and Iranian. Burrow (1955:79, 1976) supports the idea of a common change to */ʃ/ in Proto-Indo-Iranian followed by /ṣ/ retroflexion in Old Indic. Evidence for an initial output of /ʃ/ for the RUKI rule in the Balto-Slavic language group is the fact that reflexes in Slavic show both /ʃ/ and /x/ in RUKI position, with /x/ evident only when further conditioned by a following non-front vowel (see Table 8, Page 6).

An initial output of */ʃ/ is consistent with Iranian reflexes which retain the palato-alveolar sibilant in RUKI position. Further support for an initial output of */ʃ/ for the RUKI rule in Indo-Iranian comes from evidence from the Nuristani languages. Nuristani is a small isolated language family located geographically on the border between present day Indic and Iranian languages. The Nuristani group of languages is thought to be an archaic offshoot of Proto-Indo-Iranian (Masica 1991: 34) which displaced an older culture in Afghanistan around 3500-3000 BC.

The output of the RUKI rule in Nuristani languages produced reflexes with palato-alveolar /ʃ/ (after k and i), retroflex /ṣ/ (after r) and unchanged PIE /s/ (after u). (Morgenstierne 1929). The significance of the Nuristani data will be discussed further in Chapter 5.0.

In light of the data discussed above, I suggest that a single sound change is responsible for the fact that */s/ turns into */ʃ/ in RUKI environment in the satem group as a whole. In this thesis, I will present acoustic data to further support this hypothesis.

1.6 SYNCHRONIC VARIATION VERSUS DIACHRONIC CHANGE

Thus far I have discussed the RUKI rule as it applies to the diachronic change in the satem group of Indo-European languages. Another aspect of this sibilant shift is that it also applied synchronically in Old Indo-Aryan and still does apply today in Sanskrit in as far as Sanskrit remains today a spoken language. The rule as it applies in Sanskrit is that /ṣ/ is found instead of /s/ immediately after /k/, /r/ or any vowel except /a/, provided that it is not final. The most important synchronic application of RUKI is in suffixation as in *cakṣus*, 'eye' and *cakṣuṣā* 'with the eye' as compared to *manas* 'mind' and *manasā* 'with the mind'. In fact, the RUKI rule applying synchronically in this manner accounts for the great majority of /ṣ/ sounds in Sanskrit. However, in the recorded (written) language, both /s/ and /ṣ/ can occur after RUKI and both occur in positions other than after RUKI. Thus what we are dealing with synchronically is a morpho-phonemic rule rather than a phonological rule (O'Bryan 1988). This fact can be used to explain many of the apparent exceptions to the rule found in Sanskrit (Longerich 1992). This may also be the case for some apparent exceptions in Baltic as well (Andersen 1968)

The diachronic RUKI shift, like many other sound changes, probably started with a purely phonetic phase. Phonetic allophones arising within the satem group of languages were later phonologized in the separate branches (Beekes 1995:135, Andersen 1968:187). In this thesis I will deal only with the diachronic changes and the phonetic elements conditioning those changes.

1.7 CONDITIONING FACTORS

The explanation of the conditioning by such disparate triggers as a high front vowel, a high back vowel, a voiced rhotic continuant and a voiceless velar stop has not been made clear. It has commonly appeared impractical to group these four elements into a 'natural class'. The solution for some has been to propose several independent triggers yielding the same results (Allen 1954, Allen 1973, Zwicky 1970). For Balto-Slavic, Endzelin (1939:101) and Fraenkel (1950:113) consider the change of PIE */s/ to /ʃ/ to be regular only after PIE */r/ and */k/ and proposed other etymologies for words in which Lithuanian /ʃ/ follows /i/ or /u/. Holger Pedersen (1895) explained the apparent exceptions following PIE */i/ and */u/ as a secondary change of /ʃ/ to /s/ following a general RUKI shift to /ʃ/ (Pedersen 1895, Andersen 1968).

Those opting for a unified theory have trouble fitting the conditioning elements into a general RUKI natural class. The two high vowels could be considered together as causing a shift to [+high]. It is well known that /i/ has a palatalizing influence on /s/ in many languages. The back position of /u/ may cause retraction of a following dental or alveolar segment as well. The assimilating influence of /k/ has been proposed to be due to the "somewhat retracted position of the tongue in the mouth . . .. causing its tip to reach the roof of the mouth more easily at a point further back than the dental one" (Whitney 1972 [1888]:180a). Presumably, this feature could also be considered as [+high]. Martinet (1951) is willing to assign the feature [+high] to /r/, but it is not usually given this feature. Assignment of [+high] feature to /r/ would also depend on the phonetic type of 'r' that is involved. Some historical linguists opting for a unified theory have trouble fitting in either the /r/ or the /k/. Zwicky, has suggested that /k/ conditions a separate process and groups /r/ and the two vowels together. Using the feature geometry of Clements 1985 and Sagey 1986, the related synchronic RUKI rule in Sanskrit has been explained, as spreading of a [+high] feature to an adjacent dorsal node (Longerich 1994). This assumption of the conditioning feature [+high] follows Kiparsky (1981) who explained the synchronic rule using the framework of lexical phonology and morphology.

The problem with all these explanations for a unified RUKI theory is that they have tried to define the assimilation strictly on the basis of place and nature of articulation. Vennemann (1974) suggested an alternative. He proposed that the conditioning was a matter of acoustics and that RUKI forms an acoustic natural class which lowers the frequencies of the energy concentration in a following /s/. It is known that palatal and palato-alveolar sibilants have a lower noise frequency compared to dental or alveolar (Strevens 1960, Fant 1968:173, Hughes and Halle 1956). Retroflex sounds show a similar acoustic effect (Stevens and Blumstein 1975).

I would like to provide an acoustic explanation for the diachronic RUKI change by comparing the spectrographic data for /s/ following /r/, /u/, /k/ and /i/ to that of /s/ in a non-RUKI environment and by comparing the spectrographic data for /s/ in both environments to /ʃ/, /x/ and retroflex /ṣ/.

2.0 METHODS

"A picture is worth a thousand words"

2.1 PRELIMINARY STUDY

A preliminary study was conducted to establish the feasibility of the thesis project and to gather background information on the acoustic quality of isolated sibilants and of /s/ in the RUKI environment. There were four informants, whose first language was English, two male and two female. In this preliminary study, informants with varying qualities of rhotic production were chosen. One male produced a strong retroflexed /r/. Such a retroflex rhotic approximant can be alveolar or post alveolar and is produced with a raising of the tongue tip or blade with constriction in the lower pharynx (Ladefoged & Maddieson 1996: 234). The other male produced a British "dropped" /r/ which deletes /r/ in the environment of a following consonant or word boundary resulting in either pre-*r* vowel lengthening [p ɚs ----> p ɜ:s, pars -----> pa:s] or insertion of schwa [pɪɚs -----> pɪəs]. Both females produced a tongue body or "bunched" /r/ (Delattre and Freeman 1968). This sound is produced with constriction in the lower pharynx and at the centre of the palate (Ladefoged and Maddieson 1996: 234) but with no raising of the tongue tip or blade. Two additional male informants whose first languages were Czech and Russian were used to obtain data on /s/ following an apical trilled /r/. The following "words" were pronounced and recorded.

Table 13: Information Recorded			
Environment of /s/ to be tested	Phrases or words elicited		
After i and u	/isa/	/asa/	/usa/
After k	cats	axe	caps
After r	pierce	purse	parse

Spectrograms of /iʃa/, /aʃa/ and /uʃa/ and isolated /f/, /s/, /ʃ/, /ṣ/, /ç/ and /x/ were also made. The Russian speaker produced *vórs, mólson, táksa, potsadít, móps*.

All spectrogram were displayed on a Macintosh Computer using the Signalyze Speech Analysis program (InfoSignal, Inc., Seattle, Wa) and printed on an Apple LaserWriter (Apple Computer, Cupertino, Ca). Signals were recorded directly into the computer using a MacRecorder (Farallon Computing, Berkeley, Ca) analog to digital converter at 16-bit precision with a sampling frequency of 22 kHz. The spectrograms were Wide Band (8ms/125 Hz) using a Fast Fourier Transform algorithm. Spectra are Wide-band, full range (0-8800 Hz), linear frequency scale, with pre-emphasis and smoothing. The spectral y axis is a linear amplitude scale.

2.2 MAIN STUDY

2.2.1 Information Recorded

The main data collection for this study was carried out using a series of RUKI and non-RUKI pairs. Informants were asked to read a list of words which contained /s/ in RUKI and non-RUKI environments. Each RUKI word was contrasted with a similar word with only the RUKI environment changed to non-RUKI, whenever possible. Words with /-rs-/ were contrasted with those with /-ls-/; /-us-/ and /-is-/ contrasted with /-as-/, /-ɔs-/ or /-ʌs-/; and /-ks-/ contrasted with /-ps-/ and /-ts-/. The word list included several different post-/s/ environments. There were some pre- *r/l* and pre- *ks/ps/ts* vowel differences within pairs but only one, *pierce/else,* may have advantaged the RUKI environment. There was no spectral evidence that any informant had loss of any segment or produced any epenthetic segment. Initial and final words on the list were not analysed in order to eliminate lead-in and closing supersegmental changes.

Table 14: RUKI and Non-RUKI Pairs in Word List

s environment to be tested							
rs	**ls**	**us**	**is**	**as ʌs ɔs**	**ks**	**ps**	**ts**
person	Neilson	loosen	Gleason	awesome	axle	capsule	pretzel
purse	pulse	juicy	fleecy	bossy	kicks	caps	cats
farce	false	roost	least	rust	quicksand	knapsack	pizza
parson	fulsome	moose	niece	moss	talks	mops	goats
pierce	else	juice	fleece	floss			
		boost	beast	bust			

2.2.2 Informants

There were ten informants, five male and five female. All had North American English as a first language. Three males and two females were born in Newfoundland and had spent most or all of their lives here. The remaining informants were born and had lived most or all of their lives elsewhere in Canada or the USA. English speakers were chosen for this study for consistency. The objective was to discover a **relative** acoustic difference in RUKI versus non-RUKI environments. The words elicited were English words and for comparison purposes, the resultant /s/ environments could be most consistently compared using native speakers of that language. Although it would be interesting to compare the relative acoustic differences of /s/ produced by speakers of different languages, such a project was beyond the scope of this study.

2.2.3 Instrumentation

For the main study, all recordings were made on high quality magnetic tape using a Sony TC-RX77ES cassette deck and ECM Electret condenser microphone (Sony Canada Ltd). Extraneous noise was eliminated as much as possible by producing the recordings in a closed, carpeted room with no operating equipment and a minimum of external noise.

All spectrograms were displayed on a Macintosh Computer using the Signalyze Speech Analysis program (InfoSignal, Inc., Seattle, Wa) and printed on an Apple LaserWriter (Apple Computer, Cupertino, Ca). Signals from the magnetic tape were transformed using a MacRecorder (Farallon Computing, Berkeley, Ca) analog to digital converter into the computer at 16-bit precision with a sampling frequency of 22 kHz. The spectrograms were Wide Band (8ms/125 Hz) for males and Very Wide Band (5ms/200 Hz) for females using a Fast Fourier Transform algorithm. Spectra were Wide-band, full range (0-8800 Hz), linear, frequency scale, with pre-emphasis (equivalent to traditional High Shaping, HS) and smoothing.

2.2.4 Analysis

The fricative noise portions of all spectrograms were assessed for the presence or absence of an initial frequency component below 3500 Hz. In addition, each RUKI/non-RUKI pair was compared to determine if the RUKI member of each pair had: 1) an initial concentration of fricative noise energy below a frequency of 3500 Hz compared to none for the non-RUKI pair; 2) a lower continuous concentration of noise energy and; 3) greater overall intensity of the fricative noise spectra. The term "noise" refers to the aperiodic sound of the voiceless fricatives.

3.0 RESULTS

"Don't tell people how to do things. Tell them what to do and let them surprise you with their results" ----- George Patton

3.1 ISOLATED FRICATIVES

Figure 3[1] shows the Wide-band spectrogram for labio-dental /f/, alveolar /s/, palato-alveolar /ʃ/, retroflex /ṣ/, palatal /ç/ and velar /x/ produced by a female linguistics student with training in articulatory phonetics. Visible energy for the alveolar fricative /s/ can be seen from 4400 to 8000 Hz, with 2 broad areas of energy concentration at 5500-6200 Hz and 7000-7500 Hz. There is no visible energy below 3500Hz. On the other hand, palato-alveolar /ʃ/ shows a strong energy concentration below 3500 Hz at 1800-2500 Hz. The spectrogram for isolated fricative, /ʃ/, also shows visible energy at higher frequencies up to 6500 Hz with a particularly strong band at 3500-4400 Hz. This is consistent with reported analyses of fricative noise (Strevens 1960:41, Hughes and Halle 1956:305) which conclude that the main energy concentration for /s/ is always above 3500 Hz while a major concentration of energy is found below 3500 Hz for /ʃ/. The upper frequency limit for /ʃ/ is also lower than for /s/.

The results for the retroflex, palatal and velar fricatives /ṣ/, /ç/ and /x/ also show a lower upper frequency limit than for /s/ and an even lower frequency energy concentration, with the major energy bands at 2300, 3200 and 1600 Hz respectively.

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1 All spectrograms and spectra referenced in the following sections can be found in Appendix I, page 55.

Relative intensity of the same isolated fricatives shown in Figure 3 is represented in Figure 4 in the raw spectra, the peak-to-peak (1000-8000 Hz) consonantal spectra and the RMS envelope in decibels. All post-alveolar fricatives have a greater peak intensity than either the alveolar /s/ or labio-dental /f/. This intensity difference is a distinguishing acoustic characteristic (Strevens 1960) and may be used as a cue in identification along with frequency.

3.2 COMPARISON OF /s/ AND /ʃ/

Figure 5 shows the Wide-band spectrogram for the isolated segments /isa/, /asa/, /usa/ compared to those for /iʃa/, /aʃa/, and /uʃa/. Visible energy in the frequency region between 2600 and 3500 Hz can be seen in the noise spectrum for /s/ when following either an /i/ or /u/, but not following /a/. This compares to a similar energy concentration between 2600 and 3500 Hz for the palato-alveolar fricative /ʃ/ in all environments. The upper frequency limit for the fricative noise spectra of /s/ is approximately 7950 Hz following /i/, /u/, and /a/. This compares to a similar upper limit for the palato-alveolar fricative /ʃ/ following /i/ and /u/. In contrast, the upper frequency limit of /ʃ/ following /a/ is considerably lower. Thus, alveolar and palato-alveolar spectral noise patterns are more similar when following /i/ or /u/ and more different when following /a/.

3.3 ACOUSTIC CHARACTERISTICS OF S IN RUKI ENVIRONMENTS

3.3.1 Following /r/

Spectrograms illustrating the acoustic quality of /s/ following /r/ are shown in Figure 6-8. In all examples shown, the fricative noise pattern of /s/ following /r/ shows the typical high frequency energy above 3500 Hz as well as a significant noise concentration below 3500 Hz. For comparison, the matched pair word with /s/ following /l/ does not show any energy concentration below 3500 Hz. Of the 50 elicitations of /-rs-/, 46 (92%) showed fricative noise energy concentration below 3500 Hz. This compares to 4 out of 50 (8%) for /- ls-/.

The lowest continuous concentration of noise energy of /s/ following /r/ is also consistently lower compared to that following /l/ as shown in Figures 9 and 10. This is particularly evident from the informant in Figure 10 who makes a strongly retroflexed /r/ (Wells 1982: 341). For comparison, the Czech and Russian speakers with a non-palatalized apical trilled /r/ did not produce this strong lowering of /s/ noise frequency (Figure 11 & 12). Of the 50 *r/l* word pairs elicited, 31 (62%) showed a lower continuous concentration of noise energy for the RUKI member compared to the non-RUKI member of the pair. There was no significant difference in the upper frequency limit between *r/l* word pairs.

Maximum intensity for the fricative noise spectra was generally greater for /-rs-/ than for /-ls-/. Of the 50 *r/l* word pairs elicited, 19 (36%) showed a greater maximum intensity for the RUKI member compared to the non-RUKI member of the pair (see

Figure 2). This greater intensity would presumably stimulate a sensation of greater loudness in the hearer.

3.3.2 Following /k/

Spectrograms illustrating the acoustic quality of /s/ following /k/ are shown in Figure 13-15. In all examples, the fricative noise pattern of /s/ following /k/ shows the typical high frequency energy above 3500 Hz as well as a significant noise concentration below 3500 Hz. For comparison, the matched pair word with /s/ following /t/ or /p/ does not show any energy concentration below 3500 Hz. Of the 39 elicitations of /-ks-/, 39 (100%) showed fricative noise energy concentration below 3500 Hz. This compares to 3 out of 39 (8%) for /-ts-/ and 15 out of 39 (38%) for /-ps-/.

Unlike results for /-rs-/, the lower fricative noise energy concentration following /k/ did not carry through over the whole noise spectra. The lowest continuous concentration of noise energy of /s/ following /k/ was not significantly different from that for /-ts-/ or for /-ps-/, although 15% of the 78 word pairs elicited did show /-ks-/ with a lower continuous frequency. There was no significant difference in the upper frequency limit between word pairs.

Maximum intensity for the fricative noise spectra was greater for /-ks-/ compared to /-ts-/ or /-ps-/ in 17% of the word pairs elicited

3.3.3 Following /i/

Spectrograms illustrating the acoustic quality of /s/ following /i/ are shown in Figures 16-18. In all examples shown, the fricative noise pattern of /s/ following /i/

shows the typical high frequency energy above 3500 Hz as well as a significant noise concentration below 3500 Hz. For comparison, the matched pair word with /s/ following /a/, /ɔ/ or /ʌ/ does not show any energy concentration below 3500 Hz. Of the 60 elicitations of /-is-/, 54 (90%) showed fricative noise energy concentration below 3500 Hz. This compares to 9 out of 60 (15%) for the non-RUKI pair.

The lowest continuous concentration of noise energy of /s/ following /i/ is also consistently lower compared to that following /ɑ/ or /ʌ/ in Figures 16 and 17. Of the 60 word pairs elicited, 34 (57%) showed a lower continuous concentration of noise energy for the RUKI member compared to the non-RUKI member of the pair. There was no significant difference in the upper frequency limit between word pairs.

Maximum intensity for the fricative noise spectra following /i/ was not significantly greater than for the matched word pairs with /s/ following /a/ or /ʌ/.

3.3.4 Following /u/

Spectrograms illustrating the acoustic quality of /s/ following /u/ are also shown in Figures 16-18. In all examples shown, the fricative noise pattern of /s/ following /u/ shows the typical high frequency energy above 3500 Hz as well as a significant noise concentration below 3500 Hz. For comparison, the matched pair word with /s/ following /a/ or /ʌ/ does not show any energy concentration below 3500 Hz. Of the 60 elicitations of /-us-/, 48 (80%) showed fricative noise energy concentration below 3500 Hz. This compares to 11 out of 60 (18%) for the non-RUKI pair

The lowest continuous concentration of noise energy of /s/ following /u/ is also consistently lower compared to that following /ɑ/ or /ʌ/ as shown in Figures 16 and 17. Of the 60 word pairs elicited, 44 (73%) showed a lower continuous concentration of noise energy for the RUKI member as compared to the non-RUKI member of the pair. There was no significant difference in the upper frequency limit between word pairs.

Maximum intensity for the fricative noise spectra following /u/ was not significantly greater than for the matched word pairs with /s/ following /a/ or /ʌ/.

3.3.5 RUKI versus non-RUKI Environments

The single most striking spectral characteristic of /s/ in all of the RUKI environments is the presence of an initial noise frequency component below 3500 Hz. Figure 1 shows clearly that this characteristic is consistently present following /r/, /u/, /k/ and /i/ but not following /l/, /t/, /p/ or /a/, /ʌ/, /ɔ/. Other spectral characteristics which make /s/ following RUKI acoustically similar to /ʃ/ are a lower frequency component extending throughout the whole noise spectrum and a greater intensity. Figure 2 shows a comparison of RUKI and non-RUKI word pairs for all three of these spectral characteristics. Only /r/ produces a significant percent of pairs with all three.

Figure 1

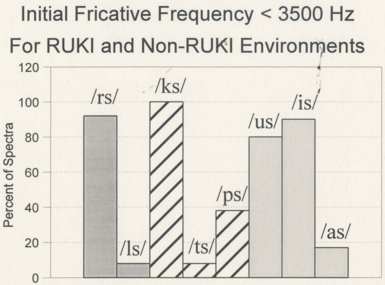


Figure 1 shows the percentage of all spectra analysed which contained an initial concentration of fricative noise at a frequency less than 3500 Hz for RUKI and Non-RUKI environments.

Figure 2

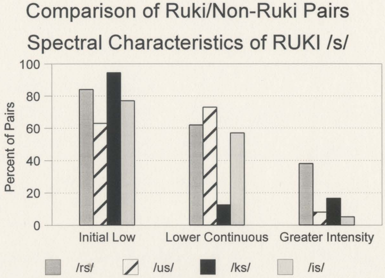


Figure 2 shows the percentage of word pairs showing a particular spectral characteristic in the RUKI word but not in the Non-RUKI word. Characteristics shown are: (1) an initial fricative frequency <3500 Hz; (2) a lower continuous concentration of noise energy and; (3) noise energy of greater intensity

lower the upper maximum. Thus it would be much more likely to be mistakenly perceived as /ʃ/ than as /ṣ/, /ç,/ or /x/, each of which has a much reduced high frequency component.

4.3 FURTHER CONDITIONING IN SLAVIC

If the initial output of the RUKI rule resulted in the palato-alveolar */ʃ/, we must look for other explanations for reflexes in Slavic with /x/. An examination of Old Church Slavic reflexes shows that sibilants in RUKI positions are further conditioned by a following element (see Table 8, Page 6). An initial RUKI output of /ʃ/ was further shifted to /x/ before the non-front vowels /o/, /u/ and /a/ but remained /ʃ/ before front vowels /i/ and /e/. The backing of the tongue-body in anticipation of the three back vowels / o, u, a/ placed the dorsal part of the tongue-body nearer the velum producing /x/ in this environment.

4.4 SUBSTRATUM EFFECT IN OLD INDIC

While the secondary shift of /ʃ/ to /x/ in Old Church Slavic was phonetically or phonologically motivated, the shift of /ʃ/ to /ṣ/ in Old Indic was probably a substratum effect. Retroflexion itself is not a very common phonological feature (Ruhlen 1976) in any of the world's languages. One can speculate, therefore, on the reason for the shift to retroflexion in Sanskrit. One suggestion is that the source of retroflexion was Dravidian (Allen 1973, Masica 1991:34, Emeneau 1962). However, there is some evidence that early Dravidian lacked a retroflex /ṣ/ but had instead a retroflex continuant transcribed as /ʐ/ or /ṟ/ (Hock 1984). Hock (1975, 1984) suggests that Indo-Aryan retroflexion can be accounted for entirely in terms of internal developments. Nevertheless, as the Indo-Aryan speakers moved into the Indian sub-continent, they did not find it empty. They must have encountered speakers of the Dravidian language family as well as the Austro-Asiatic family (represented by Munda today). There are four features which are shared by Indo-Aryan and these two language families: an unmarked SOV order, the tendency to use 'absolutives' instead of dependent or coordinate clauses, quotative construction (the use of *iti* in Sanskrit) and a **contrast between dental and retroflex consonants.**

Some argue that the common source of all of these features was Dravidian (Bhat 1973, Beekes 1995:71, Emeneau 1962). In order to account for Indic retroflexion, this convergence with Dravidian must have begun in the second millennium B.C. because retroflexion is found in the earliest documented Old Indic writings (Hock 1991). However, we do not have to assume a second millennium move by Indo-Aryans as far south as the area where Dravidian languages are spoken now. (Southern India and Sri Lanka). There is a Dravidian relic, Brahui, which is found far to the northwest in Baluchistan (Masica 1991: 40). Thus an early encounter with Dravidians is possible. One can suggest that as the Indo-Aryans moved into the Indian sub-continent bringing with them their newly shifted /ʃ/ they encountered the 'novel' retroflex sound and incorporated it into their phonemic system.

4.5 EXPLANATION OF THE OBSERVED ACOUSTIC EFFECT

The results of this study show that the /r/, /u/, /k/ and /i/ share in common an ability to lower the frequencies of the energy concentration in a following /s/. However, the mechanisms producing this acoustic effect are not the same for the four different phonemes.

4.5.1 Vowel Coarticulation

In a study of fricative-vowel coarticulation, Soli (1981) has suggested that anticipatory vowel coarticulation in the spectra of alveolar fricatives produces vowel related peaks in the region of the second formant. He found clearly defined spectral peaks at 1800 Hz in the fricative spectra of [s(i)] and peaks at 1500 Hz in the spectra of [s(u)]. These peaks are most clearly defined in the high vowels, [i] and [u], and emerge only weakly in the low vowel [a] (Soli 1981:980). Ohala (1993) states that one of the important cues in interpreting fricatives is a "special voice quality on that portion of vowels immediately abutting the fricative" (Ohala 1993:155). It is clear that vowel related acoustic cues are present in fricative noise patterns. Listeners can identify the high vowels [i] and [u] with 60%-80% accuracy given only coarticulatory cues from the fricative (Yeni-Komshian and Soli, 1981). These vowel-related fricative energy concentrations in the area of the second formant would explain the long clear F2 formant transitions seen in Figure 19A and 19B for /isa/ and /usa/.

4.5.2 Stop Release Burst

The low frequency component of the fricative noise pattern of /s/ produced after the /k/ is most likely a result of the "burst" of fricative noise produced when the voiceless stop is released. The spectrum of this noise will be similar to the spectrum of a closely homorganic fricative (Strevens 1960:46). Thus the voiceless stops /p t k/ will produce burst noise similar to /Φ s x / respectively. The burst noise of /t/ before /s/, therefore, will be identical to that of /s/ itself. The burst noise of /p/ would be similar to that of the bilabial fricative /Φ /. This fricative does produce a peak below 3500 Hz (1800-2000 Hz); however, it has the lowest intensity of any fricative (Strevens 1960:41). The burst noise of labial /p/ is therefore likely to be of very low intensity relative to /s/ and would not have a significant effect on the noise pattern of a following /s/. The noise pattern of /s/ following /k/ would be modified by the burst noise of /k/ which is homorganic with /x/. The velar fricative always has a strong peak of energy below 2000 Hz and also has an intensity almost as great as that of /s/ itself (Strevens 1960:41). Thus, the release of the voiceless stop /k/ would produce a relatively intense energy concentration below 3500 Hz in the noise pattern of a following /s/. This is just what is seen in Figure 20A and 20B in '*axe*' /æks/, an initial low frequency component of the /s/ fricative pattern lasting no more than one quarter of the total fricative duration.

4.5.3 Pharyngeal Constriction and Rhotic Lowering of F3

One of the most common acoustic characteristics of rhotic sounds in the world's languages is a strong lowering of F3 (Ladefoged & Maddieson 1996:214). In American English, this lowering of F3 is accomplished by a combination of several articulatory mechanisms (Ladefoged & Maddieson 1996:215), but one of the characteristics of both tongue body and retroflex /r/ is a palatal or palato-velar constriction (Delattre and Freeman 1968, Espy-Wilson 1992) combined with a constriction in the lower pharynx (Ladefoged & Maddieson 1996:215). If the constriction is palatal, it is made with the tongue tip or blade (retroflex /r/); if it is further back, closer to the velum, it is made with the tongue body (tongue body or bunched /r/). Acoustic models of vowel production predict a relatively low third formant when there are constrictions in the palatal or lower pharyngeal region (Ladefoged & Maddieson 1996:234, Fant 1968:173).

All informants in the main study produced either a tongue body or retroflex /r/ post-vocalically. An examination of F3 transitions can best be made in the spectrograms of the word *pierce* in which /r/ follows the high front vowel /i/. Figures 9 and 10 show a lowered F3 for the /i/ in *pierce* for a tongue body and retroflex /r/ respectively. The strong retroflex /r/ produced in Figure 10 is consistent with this informant's particular dialect resulting from south-western England origin (Wells 1982:342). Figure 9 and 10 also show an initial concentration of energy below 3500 HZ in the following fricative. In contrast, Figures 11 and 12 show the spectrogram for informants producing an apical trilled /r/. Although the trilled /r/ produces some lowering of F3, it does not produce a low frequency component in the following fricative. Neither a trilled or a flapped /r/ show pharyngeal constriction (Ladefoged & Maddieson 1996: 230). A British "dropped" /r/ with schwa reflex also results in a lowered F3 in *pierce* (Figure 21) but without producing any low frequency component in the following fricative. Production of schwa is made with a completely relaxed pharynx. It is possible that some form of pharyngeal constriction is needed along with F3 lowering to condition the RUKI shift.

The acoustic evidence presented here sheds some light on the nature of PIE /r/, at least in the Proto-satem dialect of PIE. PIE /r/ clearly conditioned a RUKI shift in a following /s/. If this shift was acoustically conditioned by a low frequency component in the following fricative, evidence from this thesis suggests that the conditioning PIE rhotic may have been a retroflex or tongue body /r/ rather than a trill or flap. This is in agreement with prescribed Sanskrit pronunciation which is described as retroflex by Pāṇini (Allen 1961:149, Cardona 1976: 17) and as *repha* a 'growl, snarl' and not "rolled" (Allen 1961: 14, Mishra 1972: 150) whereas present day Indic languages produce alveolar or retroflex trills or flaps (Allen 1961:54 , Kavadi and Southworth 1968:18, Sandhu 1986:57,173).

4.6 PERCEPTUAL REINTERPRETATIONS BASED ON ACOUSTIC SIMILARITY

For the four different RUKI phonemes, the mechanisms producing the acoustic effect are different, but the end result is the same: a modification of the acoustic quality of /s/ which makes it sound somewhat like /ʃ/. What took place next in the Proto-satem group of languages was a perceptual reinterpretation based on this acoustic similarity. By perception, I mean a combination of identification, recognition and discrimination. Hedrick (1993) has demonstrated just such a perceptual reinterpretation. In his study of the perception of synthetic fricative /s/ and /ʃ/ contrasts, he found a significantly higher proportion of /s/ responses in syllables containing /ɑ/ then in syllables containing /i/ or /u/. Given the same synthetic fricative signal, listeners were more likely to perceive the fricative as /ʃ/ in the environment of /i/ or /u/ and more likely to perceive it as /s/ when coupled with /ɑ/.

Constraints on speech production and perception lead listeners to misapprehend speech signals (Ohala 1993). Perception by a listener can be affected by articulatory constraints which affect the way a sound is uttered, or by auditory constraints which affect the way a sound is analysed. Since the listener does not have access to the mind of the speaker they are unable to determine what parts of the received signal were intended and what were not, leading to misapprehension. Any such misapprehension that leads the listener to pronounce things in a different way is potentially the beginning of a sound change.

> "Sound changes are perceptual errors which give hints as to what cues listeners use when speech perception is successful". (Ohala 1993:160)

The diachronic RUKI sound change actually represents a failure in speech perception, but this failure gives us important information about the acoustic cues that were used to distinguish the voiceless fricatives. Evidence from this thesis suggests that an initial noise frequency below 3500 Hz was just such a cue.

Such re-interpretation based on acoustic cues is not unique, as evidenced by the well know acoustic affinity between velars and labials. (Hock 1991: 96)

Table 15: Acoustic Affinity Between Velars and Labials		
Dutch **OD > ModD**	**English** **OE > ModE**	**Slavic** **Bul > Mac**
[luft] > [luxt] 'air'	[lax] > [læf], [la:f] 'laugh'	[nes-ox] > [nes-of] 'I carried'
[nif-te] > [nix-tə] 'niece'		

The acoustic cue in this case is [+grave], defined by Jakobson, Fant & Halle (1952:29) as follows: "When the lower side of the spectrum predominates the phoneme is labeled grave...". Weakening recodes the acoustic identifiability to the point where the listener can only recognize [+ grave] without being able to determine to which subclass (velar or labial) they should be assigned. It has been suggested that the perceptual reinterpretation of palatalized labials as dentals may also be based on an acoustic similarity (Hock 1991:134).

Table 16: Palatalized Labials and Dentals in Czech Tĕtak dialect
[p^yet] > [tet] 'five'
[p^yīvo] >[tīvo] 'beer'

The product of acoustic re-interpretation is a series of allophones related to a variety of specific acoustic effects. However, languages do not tolerate an indefinite proliferation of allophones and there is a tendency to treat acoustically similar sounds alike. The end result is a merger of acoustically similar allophones (Vennemann 1974:94). I believe that such a merger occurred in Proto-Balto-Slavic and Proto-Indo-Iranian dialects of PIE when /s/ shifted to /ʃ/ following /r/, /u/, /k/ and /i/.

5.0 PROPAGATION OF TEMPORAL DIALECTS THROUGH SOCIAL AND GEOGRAPHICAL SPACE

"All animals are equal but some are more equal than others"
--- Animal Farm, Aldous Huxley

5.1 CHRONOLOGY OF RUKI SHIFT

The hypothesis that the RUKI shift was an innovation within the satem group of languages with an initial output of */ʃ/ presents certain problems for the chronology of that shift with respect to the satem shift itself. If the initial RUKI output of */ʃ/ in Indo-Iranian eventually led to /ṣ/ in Old Indic (Sanskrit), why didn't the /ʃ/ resulting from PIE palatalized /k^y/ also become /ṣ/ at the same time? Conversely, why didn't Avestan or Slavic /ʃ/, in reflexes of PIE /s/ in RUKI position, become /s/ as did reflexes of PIE palatalized /k^y/ ?

Table 17: Assibilation and RUKI				
	*PIE		Sanskrit	Avestan
ASIB	*k^y	***k^y**ēnsmi 'utter, speak'	ʃaṃsāmi 'recite, tell'	sāsmi 'teach'
RUKI	*us	*(a)us- 'dawn'	uṣas	uʃa

The explanation may lie in the relative chronology of the two sound changes and the strength of the conditioning factors causing the changes. Both sound changes must have been initiated at a time when the satem group of languages were still a recognizable dialectical sub-set of Indo-European. However, assibilation of palatalized /k^y/ occurred through a series of changes which must have taken place over a considerable period of time.

(1) $*/k^y/ > */cç/ > */ç/ > /ʃ/ > /s/$ or $*/k^y/ > */cç/ > */tʃ/ > /ts/ > /s/$

The end result of this assibilation, either /ʃ/ or /s/ (see Table 17), may have occurred relatively later than the initial RUKI shift from dental/alveolar /s/ to /ʃ/. Thus at the time that the initial output of the RUKI shift, */ʃ/, became /ṣ/ in Old Indic, the output of the assibilation change may have still been in the affricate stage and not subject to this change.

In fact, the Nuristani language group provides just such an example. The Nuristani languages probably represent an intermediate phase in the RUKI sound change. When Proto-Nuristani separated from the Indo-Iranian language group, RUKI changes from PIE /s/ to /ṣ/ were complete following /r/ but remained /ʃ/ or unchanged /s/ following the other three elements. The intermediate position of Nuristani is also reflected in the fact that **assibilation of palatalized /k^y/ had only reached the affricate stage** (Morgenstierne 1943).

Table 18: Assibilation of PIE */k^y/ in Nuristani compared to Sanskrit				
Temporal change >	**PIE**	**Nuristani Dialect**		**Sanskrit**
*/k^y/ > */cç/ > /ts/ > /ʃ/	* k^{y}un- >	*[ts]una* 'dog'	Darrai Nur	*ʃunī* 'bitch'
*/k^y/ > */cç/ > /ts/ > /ʃ/	*dek^{y}m̥ >	*du[ts]* 'ten'	Waigeli	*daʃa* 'ten'

Further evidence comes from the fact that the Old Indic (Sanskrit) output of /k^y/

assibilation **does coincide** with the output of RUKI under an especially strong conditioning environment where the PIE palatalized velar is followed by a dental/alveolar stop (Table 19).

Table 19: Output of */k^y/ Assibilation in Strong Conditioning Environment			
	Temporal change >	**PIE**	**Sanskrit**
a) ASIB	*/k^y/ > */cç/ > */tʃ/ > /ʃ/	*k^ym̩tom >	ʃata '100'
b) ASIB	*/k^y/ > */cç/ > */tʃ/ > /ʃ/	*wek^y-mi >	vaʃ-mi 'I desire'
c) ASIB	*/k^yt/ > */ʃt/ > /ṣṭ/	*wek^y-ti >	vaṣ-ṭi 'he desires'
d) ASIB	*/k^yt/ > */ʃt/ > /ṣṭ/	*ok^{y}t- >	aṣṭau 'eight'
e) RUKI	*/ks/ > */kʃ/ > /kṣ/	*deks- >	dakṣ- 'right'

Assibilation of PIE */k^y/ led to Sanskrit palatal /ʃ/ except where it was further conditioned by a following alveolar stop /t/. The presence of a the following /t/ encouraged assibilation to a more fronted position and caused consonant cluster simplification of the resulting */tʃt/ to occur sooner. This produced a palatal /ʃ/ **at the same point in time** that RUKI was producing a palatal /ʃ/. The substratum effect of /ʃ/ > /ṣ/ acted on both of these palatal sibilants producing the retroflex /ṣ/ in both cases. Meanwhile, assibilation of */k^y/ to /ʃ/ in other lighter environments occurred later in time, after the RUKI change and the substratum effect was over and done with.

The spread of any sound change rule temporally and geographically is dependent on the relative strength of the conditioning environment (Bailey 1973: 68). Within any single "rule", stronger conditioning produces a change relatively earlier than a weaker environment. Thus, evidence of a retroflex output from the assibilation rule in a strong environment implies that assibilation in weaker environments took place at a relatively later time.

5.2 RUKI SOUND CHANGE IN SATEM DIALECTS

The RUKI sound change can be described as a type of acoustically conditioned assimilation affecting the satem language group. Here I am assuming a parent satem language with dialect development which eventually led to Proto-Baltic, Proto-Slavic, Proto-Iranian and Proto-Indic. Diffusion of the RUKI sound change throughout the dialects within the satem language group could be described in three different ways: 1) The RUKI sound change, in its fully generalized form, could have affected the parent language before any breakup into dialects; 2) The RUKI sound change could have taken place after distinct dialects were formed; 3) The RUKI sound change could have been present in a restricted form in the parent language and then generalized to greater or lesser extent in developing dialects depending on their date of separation from the parent language. Acoustic evidence presented in this thesis is compatible, to some extent, with all three alternatives above. However, I would support alternative three with the following arguments.

The first alternative suggests that the RUKI rule developed rather early in the parent satem language before any distinct dialects had formed. When later Proto-Balto-Slavic and Proto-Indo-Iranian dialects developed, the output of the RUKI rule was reinterpreted with some "reversions" from /ʃ/ to /s/. This reversion to the original PIE */s/ is most problematic as it would require a **second** sound change to occur independently in several dialects. This reversal would also have had to take place in an environment acoustically predisposed to remain /ʃ/.

The second alternative implies that RUKI changes occurred initially in only one of many established satem dialects and later spread from one dialect to another. This description would be compatible with a wave model of diffusion, but would require both "contact" and some degree of bilingualism across the whole satem language group after distinct daughter languages had developed. This alternative is also not consistent with the relative chronology of satem assibilation and RUKI discussed in 5.1, as it would surely suggest that the satem assibilation came chronologically earlier than RUKI..

The third alternative suggests that the RUKI sound change developed in the parent language initially in a restricted form and gradually generalized over a period of time. At various points during this time dialect groups left the main satem language group. The date of separation from the parent language would correspond to the extent of RUKI development. This alternative is compatible with acoustic evidence and is most economical in the number of independent sound changes involved. In addition, it best explains the Nuristani data. This alternative is also compatible with a wave model of sound change diffusion, but in this case requiring contact only within the still-central part of the language group. Acoustic data can be used to develop a graphical representation of this type of sound diffusion.

5.3 ACOUSTIC EVIDENCE AND THE WAVE MODEL

Temporal and geographical development of dialects within a language community can often be described using a simple wave model of diffusion. (Bailey 1973:65, Hock 1991:444). Johannes Schmidt, in the mid 19th century, was probably the first to describe linguistic changes as waves (Schmidt 1872, Fox 1995:128) as an alternative to August Schleicher's tree model. A wave model of sound change as described by C-J. N. Bailey, supposes differential operation of any sound change rule according to the strength of the specific conditioning environment. Stronger conditioning produces what Bailey calls "heavier-weighted environments" (Bailey 1973:67) and weaker conditioning produces "lighter-weighted environments". Thus, to paraphrase the quote at the beginning of this chapter "all environments in a sound change rule are equal, but some are more equal than others". **The acoustic evidence from this thesis strongly supports this model.**

Acoustic evidence demonstrates that the RUKI environment constitutes a single acoustic natural class which lowers the frequency in the noise pattern of a following fricative. However, the acoustic evidence also demonstrates that the four RUKI conditioning elements are not equal in their effect. Figure 1 shows that of the four environments, /us/ is less likely to produce an initial fricative frequency below 3500 Hz than the other three and /ks/ is most likely. Looking at other spectral characteristics which make /s/ acoustically similar to /ʃ/, Figure 2 shows that only /rs/ has all three in a significant percentage of pairs.

Thus in terms of heavier or lighter-weighted environment, the four RUKI elements could be ranked as follows:

(2)	**Heavier**	**→**	**Lighter**
	/r/	**/k/ , /i/**	**/u/**

We can now explain why /r/ is the most uniform conditioner in both Indo-Iranian and Balto-Slavic languages and why reflexes of PIE */us/ in many examples do not undergo the RUKI shift. Examining the irregularities in these languages shows that the order of regularity exactly matches the order of acoustic conditioning strength.

(3)	**most regular**	**→**	**least regular**
	/r/	**/k/ , /i/**	**/u/**

The order of regularity also varies from sub-group to sub-group within the satem group of languages. As discussed in Chapter 1, some historical linguists have questioned the connection between the RUKI change in Indo-Iranian and in Balto-Slavic. This is because there is not a complete uniformity of change in all of these related languages. Indo-Iranian shows the changes in the most complete and regular form, Slavic languages show some unshifted forms and Baltic even more.

(4)	**most regular**	**→**		**least regular**
	Indic	**Iranian**	**Slavic**	**Baltic**

The acoustic evidence demonstrated in this thesis has direct implications about the distribution of PIE dialects within the satem language group. Using a tabular representation of the wave model suggested by Bailey (1973), I can illustrate graphically the temporal and geographical development of Proto-Indo-European dialects (see Table 20).

The model in Table 20 assumes differential conditioning strengths for the four RUKI elements with /rs/ the heaviest and /us/ the weakest. This model shows the propagation of change over time and space. Each successive table illustrates the situation at a progressively later time period. Each successive column in the table represents the separation of a dialect from the central part of the language group, either geographically, socially or both. Parentheses indicate changes which are variable. Thus at Time 1, a Proto-Indo-European dialect (A) has developed which has the RUKI change variably after /r/ . Time 6 shows a dialect (F) that has regularized the change after /r/ and /k/ with variable changes after /i/ and /u/ and so forth.

5.3.1 Propagation Model

Table 20: Propagation of Temporal Dialects through Social and Geographical Space

Geographical and Social Separation

Time

Time 1		
us>uʃ		
is>iʃ		
ks>kʃ		
rs>rʃ	(r)	
Dialect	A	PIE

Time 2			
us>uʃ			
is>iʃ			
ks>kʃ	(k)		
rs>rʃ	(r)	(r)	
Dialect	B	A	PIE

Time 3				
us>uʃ				
is>iʃ	(i)			
ks>kʃ	(k)	(k)		
rs>rʃ	(r)	(r)	(r)	
Dialect	C	B	A	PIE

Time 4					
us>uʃ	(u)				
is>iʃ	(i)	(i)			
ks>kʃ	(k)	(k)	(k)		
rs>rʃ	(r)	(r)	(r)	(r)	
Dialect	D	C	B	A	PIE

Geographical and Social Separation

Time

Time 5						
us>uʃ	(u)	(u)				
is>iʃ	(i)	(i)	(i)			
ks>kʃ	(k)	(k)	(k)	(k)		
rs>rʃ	r	(r)	(r)	(r)	(r)	
Dialect	E	D	C	B	A	PIE

Time 6							
us>uʃ	(u)	(u)	(u)				
is>iʃ	(i)	(i)	(i)	(i)			
ks>kʃ	k	(k)	(k)	(k)	(k)		
rs>rʃ	r	r	(r)	(r)	(r)	(r)	
Dialect	F	E	D	C	B	A	PIE

Time 7								
us>uʃ	(u)	(u)	(u)	(u)				
is>iʃ	i	(i)	(i)	(i)	(i)			
ks>kʃ	k	k	(k)	(k)	(k)	(k)		
rs>rʃ	r	r	r	(r)	(r)	(r)	(r)	
Dialect	G	F	E	D	C	B	A	PIE

Time 8									
us>uʃ	u	(u)	(u)	(u)	(u)				
is>iʃ	i	i	(i)	(i)	(i)	(i)			
ks>kʃ	k	k	k	(k)	(k)	(k)	(k)		
rs>rʃ	r	r	r	r	(r)	(r)	(r)	(r)	
Dialect	H	G	F	E	D	C	B	A	PIE

Dialect H = Proto-Indic, Proto-Iranian Dialect G = Proto-Slavic. Proto-Nuristani
Dialect F = Proto-Baltic
Dialect A-D could be Proto-Armenian, Hittite (or any proto-centum language)

(Parentheses indicate changes which are variable)

At Time 8, Dialect H has developed, which has regular RUKI changes after all four conditioning elements. This dialect would correspond to Proto-Indic and probably Proto-Iranian. At this point dialect G would correspond to Proto-Slavic and Proto-Nuristani, dialect F to Proto-Baltic, and Dialects A-D could be Proto-Armenian, Proto-Hittite or, in fact, any proto-centum language.

This model establishes the distribution of the RUKI dialects, with Indo-Iranian being the most innovative and Baltic the most conservative. This also supports the idea of the peripheral position of Proto-Baltic within the satem group of languages. This model provides graphic illustration of the premise that linguistic rules get less general in dialects more remote from the origin.

5.3.2 Nuristani data supporting the propagation model

The Nuristani language family, located geographically on the border between present day Indic and Iranian languages, provides further support for this wave model. The output of the RUKI rule in Nuristani languages (Table 21) produced reflexes with retroflex /ṣ/ (after /r/), palato-alveolar /ʃ/ (after /k/), both /ʃ/ and /s/ (after /i/) and unchanged PIE /s/ (after /u/) (Morgenstierne 1929, Edelman 1983).

Table 21: Nuristani reflexes of PIE */s/ in RUKI environment			
PIE	**Nuristani reflex**	**Nuristani dialect**	**Sanskrit**
*rs >	*piṣṭi*, *priṣṭi* 'back'	Majegal, Titin	*prṣṭha* 'back'
*ks >	*kū[tʃ]* 'middle'	Majegal	*kukṣi* 'belly, womb'
*is >	*miʃala* 'sheep'	Ashkun	*meṣaḥ* 'ram, fleece'
*is >	*pisa* 'millet'	Titin	*piṣ-* 'crush, grind'
*us >	*tus* 'straw'	Waigeli	*tuṣa* 'straw'
Morgensteirne, 1929			

The Nuristani data suggest that this dialect group separated from the satem family (Indo-Iranian) at a time when only those RUKI changes due to the strongest conditioning elements /r/ and / k/ had become regularized. The change due to the strongest conditioner, /r/, was probably regularized first. This would have allowed the secondary shift of /ʃ/ > /ṣ/ to have developed in the RUKI environment following /r/ before the Nuristani language group became isolated.

The intermediate position of Nuristani is also reflected in the fact that the satem assibilation of palatalized /k^y/ had only reached the affricate stage (Table 18) when this dialect separated (Morgenstierne 1943).

5.3.3 Lexical Diffusion and Neogrammarian Sound Change

The Neogrammarians conceived of sound changes as regular, affecting all qualifying lexical items simultaneously, unobservable, governed only by phonetic factors and proceeding by gradual, imperceptible steps (Kiparsky 1989, Hock 1991:631).

The general diffusionist theory (Wang & Cheng 1977, Hock 1991: 646-650, Labov 1969, Labov 1994), on the other hand, asserts that sound change originates in a relatively small number of lexical items, becomes variable in similar phonetic classes and is regularized only in the final outcome. Relatively superficial changes tend to be generalized in a sweeping, rule-governed fashion consistent with Neogrammarian ideas of sound change, while more abstract changes which affect the lexical representation of given forms display a tendency toward diffusionist implementation (Labov 1981).

Assimilation and weakening constitute the bulk of phonetic processes which typically result in regular sound change (Hock 1991:653). This type of sound change is usually imperceptible and has no exceptions (fast and complete). On the other hand, acoustically-based processes, dissimilation and metathesis produce sound changes which are quite noticeable and result in irregular output (slow and incomplete).

The acoustic conditioning presented in this thesis can best be represented by a diffusionist description of sound change as opposed to a Neogrammarian viewpoint.. The RUKI sound change developed in the parent satem language initially in restricted form after the strongest conditioner, /r/. The change was gradually regularized for all four conditioning phonemes over a period of time. At various points during this time dialect groups left the main language group and the date of separation from the parent satem language corresponds to the extent of RUKI development. The dialect propagation model, shown in Table 20 , provides a **graphical representation of such a diffusionist view of sound change.**

6.0 SUMMARY

"I may not have gone where I intended to go, but I think I have ended up where I intended to be." — Douglas Adams

The RUKI rule describes the diachronic shift in the satem group of Indo-European languages in which PIE */s/ following */r, u, k or i/ became /ʃ/ in Baltic and Iranian, /x/ in Slavic and retroflex /ṣ/ in Old-Indic. The objective of this study was to describe the diachronic development of the RUKI shift by acoustic examination of the conditioning environments producing this shift.

6.1 ACOUSTIC DATA

The acoustic data presented here has demonstrated that RUKI phonemes produce an initial noise energy component below 3500 Hz in a following /s/. In addition, RUKI elements can also cause a lower frequency continuous concentration of noise energy and a greater noise intensity in a following /s/ compared to non-RUKI phonemes. The resulting fricative sound in the RUKI environment may be acoustically similar to post-alveolar fricatives which have a major low frequency component. While the RUKI environment lowers the noise frequency of a following /s/, it does not lower the upper maximum. Thus it is more likely to be mistakenly perceived as palato-alveolar /ʃ/ than any other post-alveolar fricative since only /ʃ/ has a major high frequency component as well as noise frequency below 3500 Hz.

Based on spectrographic analysis of RUKI and non-RUKI word pairs, the relative strengths of the acoustic conditioning of the RUKI elements were determined. The strongest conditioner was /r/. Only /r/ produced a significant percentage of word pairs with all three of the acoustic characteristics which make /s/ sound similar to /ʃ/. The next strongest conditioning phonemes are /k/ and /i/, with /u/ being the weakest

6.2 THE DIACHRONIC RUKI SOUND CHANGE

The four RUKI phonemes can be considered together as forming an acoustic natural class which lowers the noise frequency of a following /s/. This fact supports the inclusion of all four conditioning elements in a single RUKI rule. The acoustic data in this thesis also support the theory that the development of the RUKI sound change was a common innovation within the satem group of languages. Acoustic evidence suggests that the initial output of the RUKI sound change in the Proto-satem group of languages was palato-alveolar /ʃ/. The output in Slavic was further shifted to /x/ before non-front vowels and to /ṣ/ in Old Indic, due to a Dravidian substratum effect, with /ʃ/ remaining in Baltic and Iranian.

Examination of the relative strengths of the RUKI elements showed that the strongest acoustic conditioner was /r/, followed by /k/ and /i/, with /u/ being the weakest. This relative strength of the acoustic conditioning exactly reflects the relative regularity of the RUKI shift in both Indo-Iranian and Balto-Slavic languages with the most regularity following /r/ and the least regularity following /u/.

All four RUKI phonemes modified the acoustic quality of a following /s/ to make it sound somewhat like /ʃ/. The diachronic RUKI sound change was most likely initiated by a perceptual reinterpretation based on this acoustic similarity. Although the initial product of this acoustic reinterpretation may have been a series of allophones related to a variety of specific acoustic effects, the end result was a merger of acoustically similar allophones to produce /ʃ/ as the uniform output of the RUKI rule in the Proto-satem language group.

6.3 THE WAVE MODEL OF SOUND CHANGE

Arguments presented in this thesis support a diffusionist or Labovian description of sound change and reinforce the wave theory of dialect propagation. Propagation of dialects within the satem group of languages can be explained using a wave model based on the relative acoustic strength of RUKI conditioning elements. Using the idea of "lighter" and "heavier" conditioning elements, as described by Bailey (1973), a model of the diffusion of the RUKI sound change over time can be constructed. It places Proto-Indo-Iranian at the centre of innovation with respect to the RUKI shift and Proto-Baltic at the periphery. The model so constructed reflects the temporal and geographic separation of dialects within the satem language family.

REFERENCES

Allen, W.S. 1954. Retroflexion in Sanskrit: Prosodic technique and its relevance to comparative statement. *School of Oriental African Studies Bulletin* 16:556-565.

Allen, W.S. 1961. *Phonetics in Ancient India*, Oxford: Oxford University Press.

Allen, W.S. 1973. χθών, RUKI, and related matters. *Transactions of the Philological Soc*iety, Oxford: Blackwell, 98-126.

Andersen, H. 1968. IE *s after i, u, r, k in Baltic and Slavic. *Acta Linguistica Hafniensia* 11:171-190.

Bailey, C-J. N. 1973. *Variation and Linguistic Theory*. Arlington, Virginia: Center for Applied Linguistics.

Beekes, R.S.P. 1995. *Comparative Indo-European Linguistics*. Amsterdam: John Benjamins.

Bhat, D.N.S. 1973. Retroflexion: an areal feature. Working Papers on Language Universals. Stanford: Stanford U. Press. 27-67.

Burrow, T. 1955. *The Sanskrit Language* London: Faber and Faber.

Burrow, T. 1976. Sanskrit words having dental -s- after i, u, and r. In *Studies in Greek, Italic and Indo-European Linguistics*. Eds Davies, A.M. and Meid, W., Innsbruck: Innsbrucker Beitrage zur Sprachwissenschaft, 33-41.

Cardona, M. 1976. *Pāṇini: His Work and its Traditions*. Delhi: Motilal Banarsidass.

Clements, G.N. 1985. The geometry of phonological features. *Phonology Yearbook* 2:225-252.

Delattre, P. and Freeman, D. 1968. A dialect study of American R's by X-ray motion picture. *Language* 44:29-68.

Edelman, E.I. 1983. *The Dardic and Nuristani Languages*. Moscow: Nauka Publications.

Emeneau, M.B. 1962. Bilingualism and structural borrowing. *Proceedings of the American Philosophical Society* 106(5): 430-442.

Endzelin J. 1939. Uber den slavisch-baltishen Reflex vom idg. sk. *Zeitscrifte für slavishe Philologie* 16: 101-115.

Espy-Wilson, C.Y. 1992. Acoustic measures for linguistic features distinguishing the semivowels /w j r l/ in American English. *J Acoustic Society America* 92(3):736-757.

Fant, D.G.M. 1968. Analysis and synthesis of speech processes. In *Manual of Phonetics*. Ed. Malmberg B., Amsteram: North Holland 173-277.

Fox, A. 1995. *Linguistic reconstruction.* Oxford: Oxford University Press. 128-133.

Fraenkel E. 1950. *Die baltischen Sprachen.* Heidelberg: Winter.

Goldman, R.P. and Sutherland, S.J.1987. *Devavāṇīpraveśikā: An Introduction to the Sanskrit Language*. Berkeley: Center of South and Southeast Asia Studies, University of California.

Hedrick, M.S. 1993. Effect of relative amplitude of frication on perception of place of articulation. *J Acoustic Society America* 94:2005-2026.

Hock H.H. 1975. Substratum influence on (Rig-Vedic) Sanskrit. *Studies in the Linguistic Sciences* 5(2): 76-125.

Hock, H.H. 1984. Rig-Vedic convergence of Indo-Aryan with Dravidian? Another look at the evidence. Studies in the Linguistic Sciences 14(1): 89-108.

Hock, H.H. 1986. *Principles of Historical Linguistics*. New York: Mouton de Gruyter.

Hughes, G.W. and Halle, M 1956. Spectral properties of fricative consonants. *J Acoustic Society Am*erica 28(2):303-310.

Jakobson, R., Fant, G. & Halle, M.. 1952. *Preliminaries to Speech Analysis*. Cambridge, MA: MIT Press.

Kavadi, N.G. and Southworth, F.C.1968. *Spoken Marathi*. Philadelphia: University of Pennsylvania Press.

Kiparsky, P. 1981. *Lexical Morphology and Phonology*. Cambridge, Mass, M.I.T Press. 120-133.

Kiparsky, P. 1989. Phonological change. In *Linguistics: The Cambridge Survey. I Linguistic Theory: Foundations*, Ed Newmeyer, F.J 363-415.

Ladefoded, P and Maddieson I. 1996. *The Sounds of the World's Languages*. Oxford: Blackwell.

Labov, W. 1969. The internal evolution of linguistic rules. In *Linguistic Change and Generative Theory*. Eds R. Stockwell & R.K.S. Macaulay, Bloomington: Indiana University Press 101-171.

Labov, W. 1981. Resolving the neogrammarian controversy. *Language* 57:267-308

Labov, W. 1994. *Principles of Linguistic Change: Internal Factors*. Oxford: Blackwell

Longerich, L. 1992. S retroflexion in Sanskrit: the RUKI Rule. Manuscript, St. John's Newfoundland: Memorial University of Newfoundland.

Longerich, L. 1994. A phonological analysis of retroflexion of n and s in Sanskrit. Manuscript, St. John's, Newfoundland: Memorial University of Newfoundland.

Mann, S.E. 1984. *An Indo-European Comparative Dictionary. Fasicle 1-11* Hamburg: Helmut Buske Verlag.

Martinet, A. 1951. Concerning some Slavic and Aryan reflexes of IE s. *Word* 7:91-95.

Masica, C.P. 1991. *The Indo-Aryan Languages*. Cambridge: Cambridge University Press.

Meillet, A. 1967 [1922]. *The Indo-European Dialects*, trans by Samuel N. Rosenberg, Montgomery: University of Alabama Press.

Mishra, V. 1972. *A Critical Study of Sanskrit Phonetics.* Varanasi, India: Chowkhamba Sanskrit Series.

Monier-Williams, M. 1993. *Sanskrit-English Dictionary.* Delhi: Motilal Banarsidass

Morgenstierne, G., 1929. The language of the Ashkun Kafirs. *Norsk Tidsskrift for Sprogvidenskap*.2:192-289

Morgenstierne, G. 1943. Indo-European k' in Kafiri. *Norsk Tidsskrift for Sprogvidenskap* 13:225-238.

Ohala, J. 1993. Sound change as nature's speech perception experiment. *Speech Communication* 13:155-161.

O'Bryan, M. 1988. Exceptions and the unity of phonological processes. In *Modern Studies in Sanskrit*, Ed. Singh R., New Delhi: Bahri Publications 189-198.

Pedersen, H. 1895. Das indogermanische s im Slawishen. *Indogermanische Forschungen* 5:33-87.

Pokorny, J. 1959-69. *Indogermanisches Etymologisches Wörterbuch* , Vol I & II. Bern: Francke.

Ruhlen, M. 1976. *A Guide to the Languages of the World.* Stanford: Stanford University.

Sagey E. 1986. The representation of features and relations in nonlinear phonology. PhD dissertation. Cambridge, Mass: M.I.T. Press.

Sandhu, B.S. 1986. *The Articulatory and Acoustic Structure of the Panjabi Consonants.* Patiala, India: Publication Bureau of Punjabi University.

Schmidt, J. 1872. *Die Verwandtschaftsvverhältnisse der indogermanishen Sprachen.* Weimar: Böhlau.

Soli, S.D. 1981. Second formants in fricatives: Acoustic consequences of fricative-vowel coarticulation. *J Acoustic Society Am*erica 70(4):976-984.

Stevens, K.N. and Blumstein, S.E. 1975. Quantal aspects of consonant production and perception: a study of retroflex consonants. *J. of Phonetics.* 3:215-233.

Strevens, P. 1960. Spectra of fricative noise in human speech. *Language and Speech,* 3(1):32-49.

Szemerényi O. 1996 [1990]. *Introduction to Indo-European Linguistics* [*Einführung in die vergleichende Sprachwissenschaft].* Oxford:Clarendon Press.

Uhlenbeck, C.C. 1977. *A Manual of Sanskrit Phonetics.* New Delhi: Munshiram Manoharial.

Vennemann, T. 1974. Sanskrit RUKI and the concept of a natural class. *Linguistics* 130:91-97.

Walde, A. and Pokorny J. 1927-32. *Vergliechendes Wörterbuch der indogermanischen Sprachen*, 3 vols. Berlin: de Gruyter.

Wang, W. S-Y. & Cheng, C-C. 1977. Implementation of phonological change: the Shuangfeng Chinese case. In *The Lexicon in Phonological Change*, Ed W. Wang, The Hague: Mouton 86-100.

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

Whitney, W.D. 1972 [1888] *A Sanskrit Grammar*. Cambridge, Mass: Harvard Univ. Press.

Yeni-Komshian, G. and Soli, S.D. 1981. Recognition of vowels from information in fricatives: Perceptual evidence of fricative-vowel coarticulation. *J Acoustic Society America* 70(4):966-975.

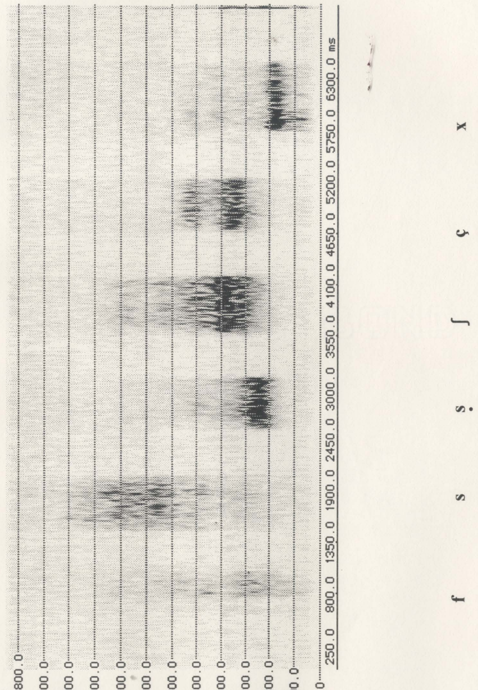
Zwicky, A. 1970. Greek-letter variables and the Sanskrit ruki class. *Linguistic Inquiry* 1:549-554.

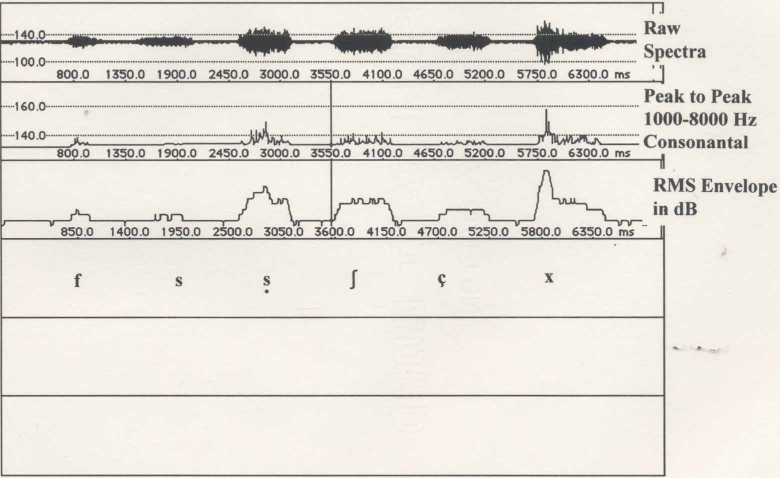
APPENDIX 1

Spectrograms and Spectra

Figures 3-21

Figure 3
Isolated Fricatives
Spectrogram





Isolated Fricatives
Spectra and RMS Envelope

Figure 5
RUKI Vowel Environment for /s/ and /ʃ/

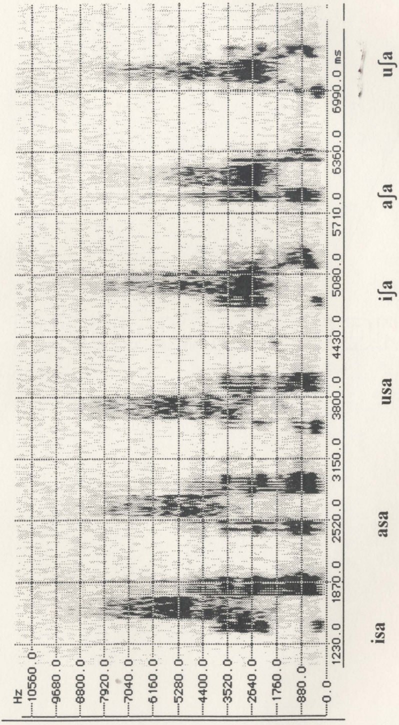


Figure 6
/rs/ Environment Compared to /ls/

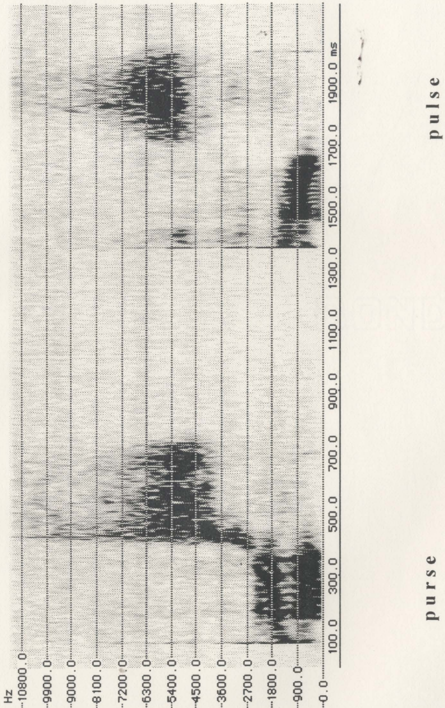


Figure 7
/rs/ Environment Compared to /ls/

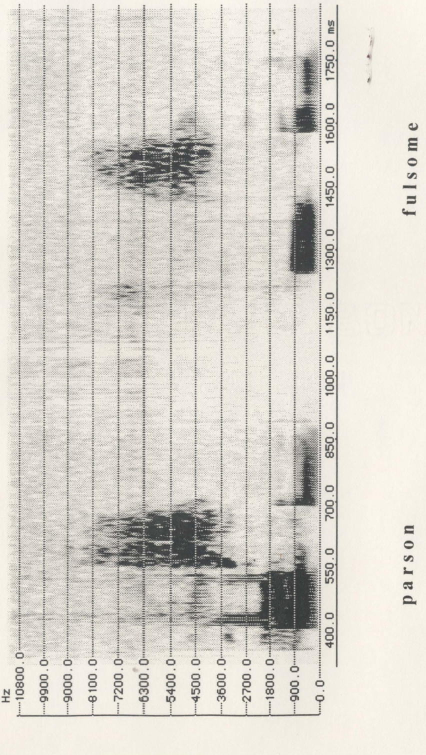
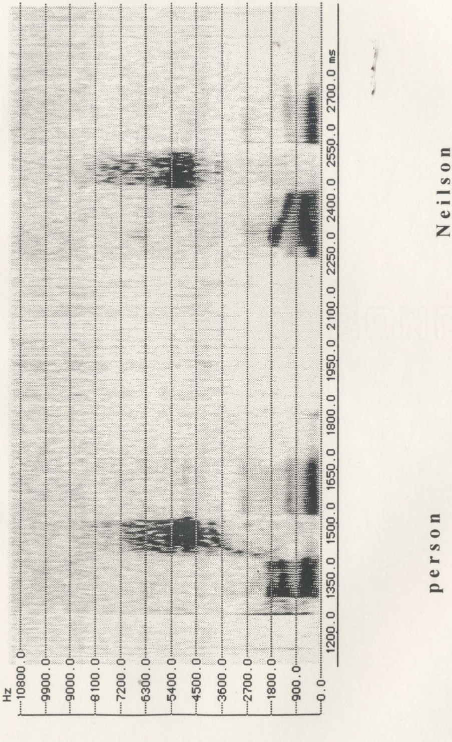
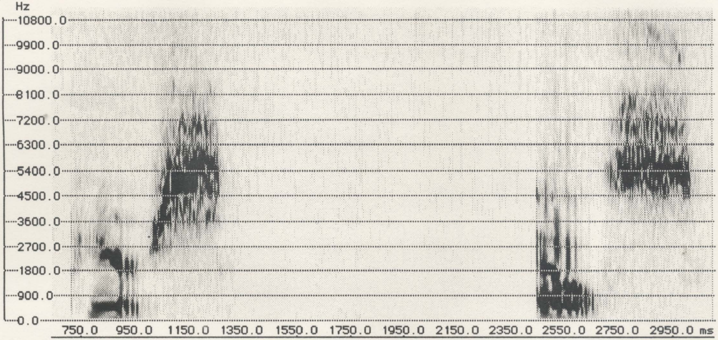


Figure 8

/rs/ Environment Compared to /ls/

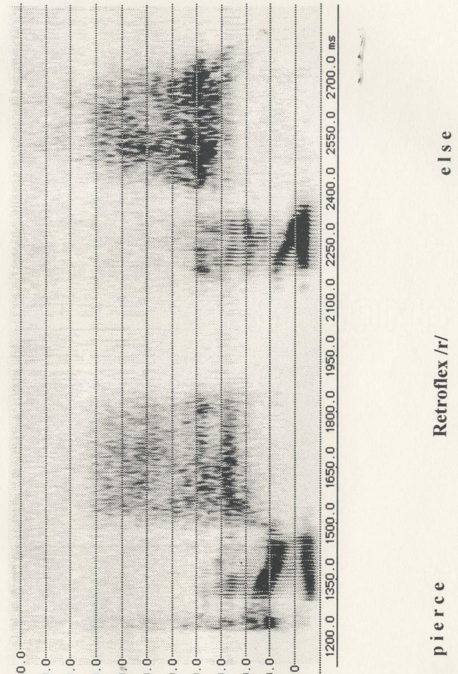


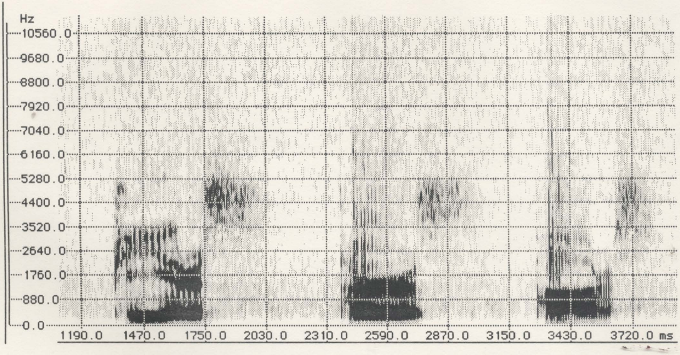


pierce **Tongue Body /r/** **else**

Figure 9
Illustration of /rs/ for Tongue Body /r/

Figure 10
Illustration of /rs/ for Retroflex /r/





Czech Trilled /r/

p i e r c e **p u r s e** **p a r s e**

Figure 11
Illustration of /rs/ Trilled /r/
for Czech Speaker

Figure 12
Illustration of /rs/ Trilled /r/
for Russian Speaker

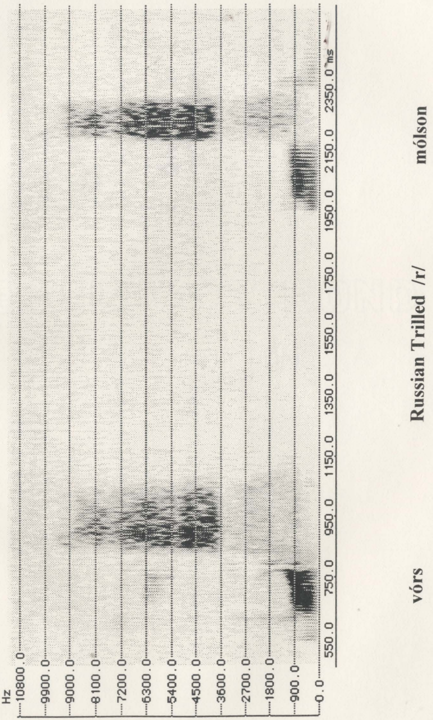


Figure 13
Example of /ks/ Compared to /ts/ and /ps/

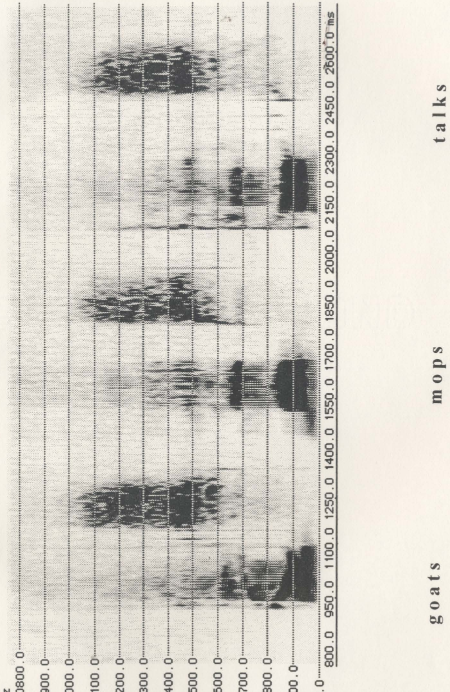
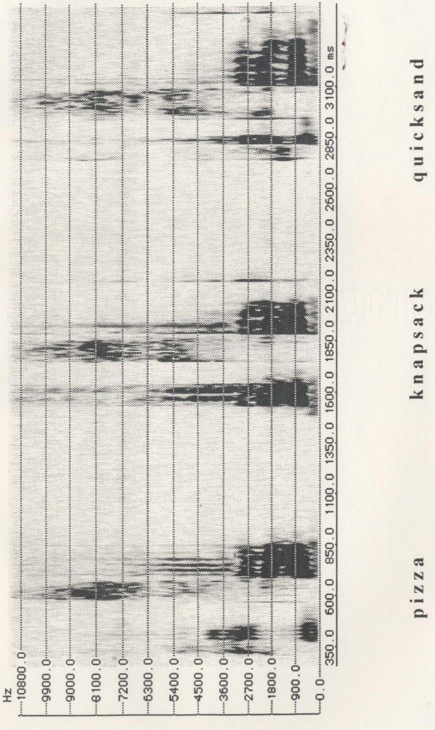


Figure 14
Example of /ks/ Compared to /ts/ and /ps/



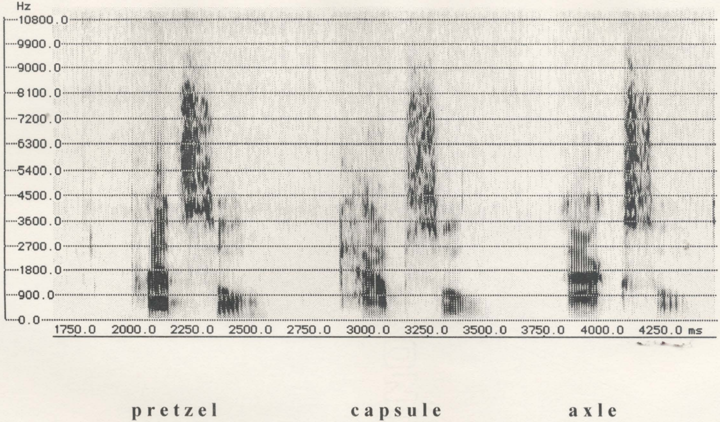
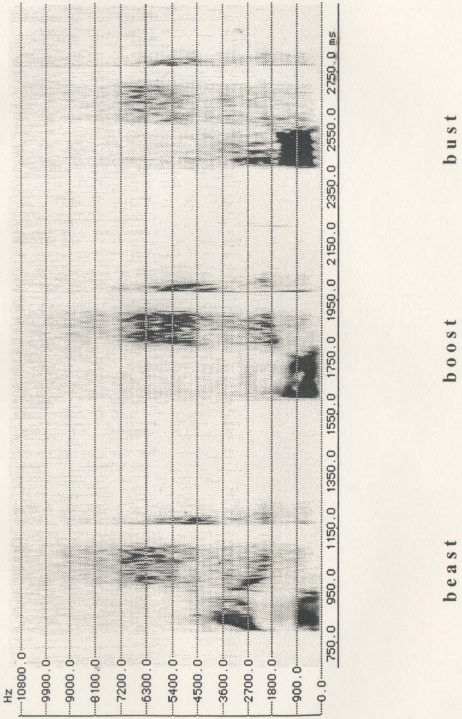


Figure 15
Example of /ks/ Compared to /ts/ and /ps/

Figure 16
Example of /is/ and /us/ Compared to /ʌs/



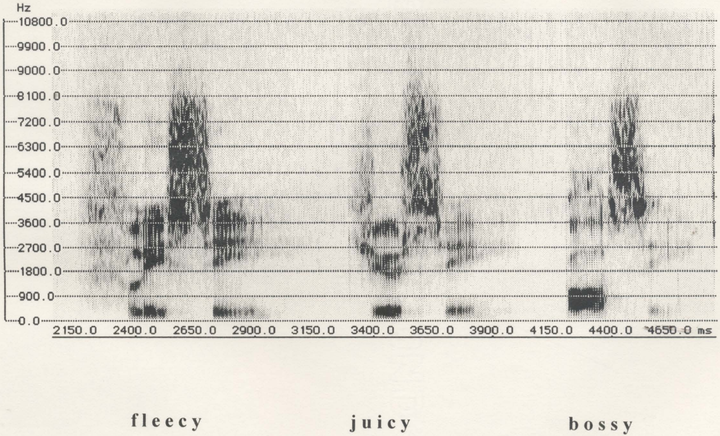
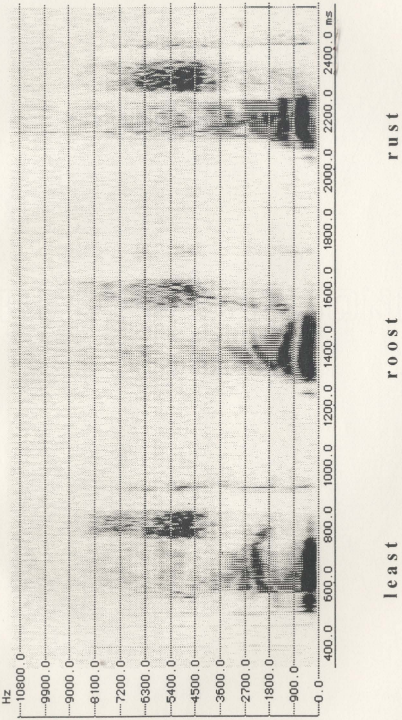


Figure 17
Example of /is/ and /us/ compared to /ɑs/

Figure 18
Example of /is/ and /us/ compared to /ʌs/



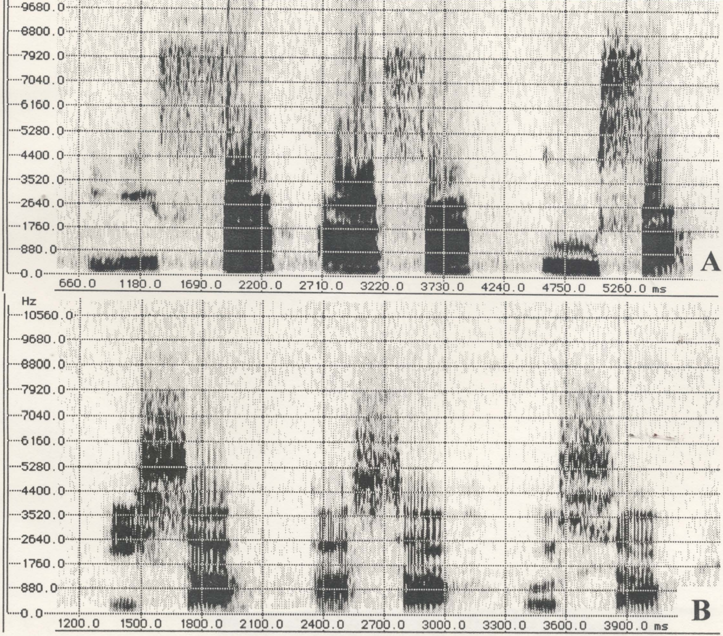
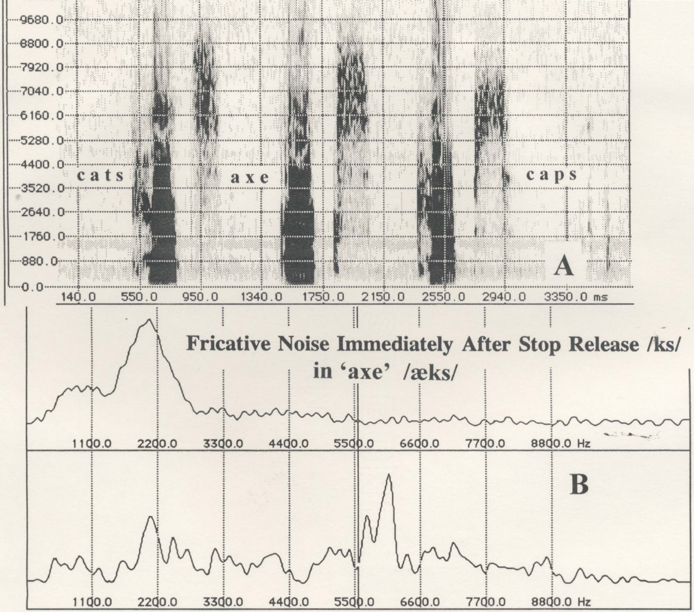


Figure 19
Illustration of Vowel Related Transitions for /is/ and /us/



Fricative Noise 50 msec After Stop Release /ks/

Figure 20
Illustration of Fricative Noise Pattern after /ks/
Spectrogram and Spectral Sections

Figure 21
Example of 'dropped' British /r/