The Phonetics and Phonology of Retroflexes

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phone: +31 30 253 6006
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The Phonetics and Phonology of Retroflexes

Fonetiek en fonologie van retroflexen
(met een samenvatting in het Nederlands)

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Silke Renate Hamann

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Promotoren: Prof. dr. T. A. Hall (Leipzig University)
Prof. dr. Wim Zonneveld (Utrecht University)

Contents

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Lastly and most importantly I want to thank Paul for the happiness he has brought to my life outside of linguistics.

Abbreviations and symbols

Abbreviations

ABL	ablative case
AG	agent
AGR	agreement
AUG	augmented
C	consonant
DAT	dative case
DEF	definite
FG	Feature Geometry
FP	Functional Phonology
NOM	nominative case
OT	Optimality Theory
PASS	passive
POSS	possessive
PRES	present tense
PS	person
RE	realis
REM	remote
SG	singular
SUP	superlative
V	vowel

Symbols

//	underlying representation
[]	phonetic representation
ˈ	primary stress
ˌ	secondary stress
.	syllable boundary
$(_\omega\ )_\omega$	prosodic word boundaries
*	violation of a constraint
!	fatal violation of a constraint
☞	optimal candidate

1 Introduction

At the outset of this dissertation one might pose the question why retroflex consonants should still be of interest for phonetics and for phonological theory since ample work on this segmental class already exists. Bhat (1973) conducted a quite extensive study on retroflexion that treated the geographical spread of this class, some phonological processes its members can undergo, and the phonetic motivation for these processes. Furthermore, several phonological representations of retroflexes have been proposed in the framework of Feature Geometry, as in work by Sagey (1986), Pulleyblank (1989), Gnanadesikan (1993), and Clements (2001). Most recently, Steriade (1995, 2001) has discussed the perceptual cues of retroflexes and has argued that the distribution of these cues can account for the phonotactic restrictions on retroflexes and their assimilatory behaviour. Purely phonetically oriented studies such as Dixit (1990) and Simonsen, Moen & Cowen (2000) have shown the large articulatory variation that can be found for retroflexes and hint at the insufficiency of existing definitions.

What does the present dissertation contribute to the topic of retroflexes that is new and has not been said before? There are four main points, summarized under (1).

(1) (a) a new phonetic definition
(b) description of cross-linguistically common phonological processes
(c) phonetic grounding for these processes
(d) phonological analysis of these processes (in OT)

First of all, a new phonetic definition of ‘retroflex’ is proposed based on four common articulatory properties, see (1a). This definition is necessary in the light of very recent phonetic work such as Simonsen et al. where the class of Norwegian retroflexes is claimed to be non-retroflex since it does not fall within the traditional definition of a tongue tip bent backwards. This claim ignores the fact that the segments under question share a number of articulatory characteristics with retroflexes in other languages and behave phonologically like retroflex segments. The most notable of the four defining properties proposed here is the retraction of the tongue body, which I claim to be present in all retroflex articulations in all languages, opposing Bhat’s (1973) claim to the contrary. An implication of my claim is that retroflex segments cannot be secondarily palatalized, since the two gestures of tongue back retraction and palatalization are not producible at the same time. The four properties yield a less restricted definition of ‘retroflexion’ than traditional ones and allow the inclusion of segments that were previously not classified as retroflex, e.g. the Russian post-alveolar fricative.[1]

Secondly, this dissertation describes in detail phonological processes of retroflexes that occur cross-linguistically, see (1b), giving examples from several language families. The processes were found by comparing grammars from all possible language families that employ retroflex segments. This aspect of my dissertation can be viewed as an extension of Bhat's (1973) examples of such processes. Furthermore, the phonological processes identified provide a tool to determine whether segments with a questionable retroflex status, e.g. [ʃ] in Russian, share not only the phonetic properties with retroflex segments in other languages, but also behave phonologically like other retroflexes.

Thirdly, a phonetic grounding of the phonological processes described under (1b) is provided, see (1c). Several cross-linguistic regularities involving retroflexes are argued to be attributable to their common articulatory properties as defined for (1a), and to their resulting restrictions on co-articulation. In contrast to Bhat (1973), the grounding proposed here is not restricted to articulation; a number of processes are shown to be caused by perceptual similarity between input and output segments.

Lastly, a phonological analysis of the phonological processes is given, see (1d). This is done in the framework of Optimality Theory (henceforth: OT, Prince & Smolensky 1993), which offers the possibility to express conflicting tendencies such as articulatory simplicity and perceptual salience in terms of constraint interaction. In particular, a slightly modified version of Boersma's (1998, 2003b) Functional Phonology is employed. This framework does not only include perceptual information accounting for phonological processes, but also assumes underlying perceptual representations, from which articulatory specifications are derived. This departs strongly from phonological accounts employing traditional articulatory feature representations, as e.g. in the theory of Feature Geometry (Clements 1985, Sagey 1986), which are often used in traditional OT accounts. Furthermore, the Functional Phonology framework departs from recent, more phonetically oriented accounts such as Flemming (1995) and Steriade (1995, 2002), which allow perceptual information only additionally to articulatory representations. Boersma's Functional Phonology framework as applied in this work is supplemented by an articulatory model with four articulators, the tip, blade, middle, and back of the tongue. These tongue parts are assumed to be partly dependent on each other, in contrast to phonological models of the articulatory apparatus such as Feature Geometry, or phonetic models such as Articulatory Phonology (Browman & Goldstein 1989, 1992), in which a complete independence of the articulators is assumed. This dependence can explain the non-occurrence of specific gesture combinations, which can again account for some of the behaviour of retroflexes.

In addition to these four main points, which will be treated in separate chapters, there are two recurrent topics in this dissertation that are not dealt with separately. These are the markedness of the class of retroflexes including the alleged

[1] Keating (1991) suggests that the Russian post-alveolar fricative could be considered retroflex but does not state on which grounds, i.e. a definition of retroflex including this sound is missing in her article.

weakness of their cues, and the relation between phonetic cues and phonological features. These latter points are elaborated in the following subsections 1.1 and 1.2. Section 1.3 gives an overview of the structure of this dissertation.

1.1 Markedness of retroflexes

In this section, the cross-linguistic markedness of retroflexes is described, and two possible reasons for this markedness are investigated: their articulatory complexity and the weakness of their cues. It will be shown that the complexity of their gesture can be made responsible for their relatively rare occurrence cross-linguistically, but that there is no evidence for a universal *perceptual* markedness of retroflexes.

Retroflexes occur relatively infrequently cross-linguistically, for instance only 11% of the languages of the world have a retroflex stop (Ladefoged & Bhaskararao 1983: 292). Furthermore, typically only large segment inventories have a retroflex class, i.e. at least another coronal segment (apical or laminal) is present, as for instance in Sanskrit, Hindi, Norwegian, Swedish, and numerous Australian languages. Maddieson's (1984) database of 317 languages mentions only one exception to this general tendency, namely the Dravidian language Kota, which has a retroflex as its only coronal fricative. An overview of coronal inventories of the languages of the world with respect to retroflex classes and inventory size is given in table 1.1, based on Maddieson (1984).[2]

Table 1.1 Inventories in Maddieson's (1984) database sorted according to manner classes (stops, nasals, and fricatives), place of articulation (either with or without a retroflex segmental class), and the number of coronal places used by each language in these classes (from none up to four).

manner	coronal inventories	0	1 place	2 place	3 place	4 place
stops	without retroflex	1	230	52	3	0
	with retroflex		0	21	5	5
nasals	without retroflex	10	176	108	3	0
	with retroflex		0	7	7	6
fricatives	without retroflex	29	127	127	15	0
	with retroflex		1	5	10	2

According to Greenberg (1978) a marked structure occurs cross-linguistically less often than its unmarked counterpart and the marked structure implies the presence of

[2] The data from Maddieson's (1984) investigation give a rough overview, however are not precise if one looks at the details: Norwegian, for instance, is counted as a language with retroflex plosive and nasal, but non-retroflex fricative.

the unmarked counterpart within a language. The distribution of retroflexes given in table 1.1 can be interpreted as an indication of the markedness of this class.[3]

The markedness of a segmental class is often explained phonetically by its articulatory complexity (see Chomsky & Halle 1968: 300, among others): a segmental class is marked because it is more difficult to articulate compared to a class that is easier to articulate. Applying this articulatory grounding of markedness to the class of retroflexes, it can be stated that retroflexes are more marked than apical alveolars (or dentals),[4] since retroflexes involve a raising and displacement of the tongue tip towards the post-alveolar region, whereas an apical alveolar involves only a tongue tip raising. The articulatory complexity can hence account for the restricted occurrence of the retroflex class.

Within the OT approach applied in this book, markedness is formalized by imposing that constraints militating against the articulation of more complex segments are higher ranked than those militating against the articulation of less complex segments. For retroflexes the following constraint hierarchy can be assumed, see (2) (along the line of Prince & Smolensky's 1993: 181 domination hierarchy and Boersma's 1998: 152 *GESTURE constraints).

(2) *RETROFLEX >> *ALVEOLAR

In traditional OT work, hierarchies as in (2) are assumed to be part of Universal Grammar and present in the phonology of every language. They interact with language-specific rankings of faithfulness constraints, which determine the actual segmental inventory of a language: if a language has faithfulness constraints that are lower ranked than the respective markedness constraints in the hierarchy in (2), then neither a retroflex nor an alveolar segmental class emerges. If, on the other hand, the faithfulness constraint for a segmental class is higher ranked than its respective markedness constraint, then this class is present in a language.

In line with traditional OT theory, I state that the hierarchy in (2) is universal and can account for cross-linguistic variation. In contrast to common belief, I argue that its universality is based in its phonetic groundedness, and not in its existence in a separate module called Universal Grammar.

What can also be found in the OT literature are rankings of markedness constraints that are not phonetically grounded. Coronals, for instance, are often argued to be less marked than labials or velars (see e.g. Paradis & Prunet 1991) because they occur cross-linguistically more often and occur in sites of neutralization (e.g. assimilation processes).[5] A constraint hierarchy formalizing this observation is presented in (3)(e.g. Prince & Smolensky 1993: 181).

(3) {*LABIAL; *DORSAL} >> *CORONAL

[3] A further indication for the markedness of retroflexes is their late acquisition, compared to other segmental classes. Acquisitional studies addressing retroflexes are few, but Lobacz (1996) reports that in Polish the retroflex fricative is acquired much later than the dental fricative.

[4] Here and throughout the dissertation the shorthand 'apical alveolar' stands for both apical alveolar and apical dental articulations.

[5] These observations have led several phonologists (Archangeli 1988, Davis 1991, and others) to propose an underspecification of the coronal class.

However, the markedness hierarchy in (3) is not grounded in articulation since it is impossible to know whether articulations with one articulator, e.g. the lips, are more difficult to produce than articulations with another articulator, e.g. the tongue tip or blade. For this reason, the frequently assumed universality of hierarchies like the one in (3) is doubted here, and they are considered irrelevant for the markedness considerations concerning retroflexes.

Phonologists like Flemming (1995, 1999), Hamilton (1996), and Padgett (2001, 2003) argue that it is necessary to include perceptual information in phonological accounts of segmental classes, and therefore assume a perceptual markedness of segments. The relative notion of perceptual markedness can be defined in two ways: either as a universal relation between a perceptually more and a perceptually less salient segment class (similar to the articulatory markedness hierarchy in (2)) as is done by Hamilton, or as an inventory-specific comparison of the perceptual distance between segments, where perceptually more distant segment inventories are less marked, as by Flemming and Padgett.

The first notion of perceptual markedness can often be found in the phonetic literature, where the term 'weak feature' is used to denote a feature that is perceptually less salient than others and is detected by the auditory system only after the so-called robust features (Stevens & Keyser 1989). In this sense, weak features are perceptually marked, a generalization that is attested by Ohala's (1993: 89) remark that the distinction between robust vs. weak features correlates nicely with the way segment inventories in languages are constructed: "those with a small number of phonemes use the robust features almost exclusively; those with many phonemes use the same robust features but also exploit weaker, slower features". According to this definition, retroflexion should be considered perceptually weak or marked since it occurs rarely and even then only in large inventories. However, no perceptual evidence could be found that perceptual cues of retroflexion are harder to detect than those of any other place of articulation (as illustrated in chapter 3 below). Therefore, perceptual markedness of retroflexes according to this universal notion will not be assumed in this dissertation. If additional information restricts or adds to the perceptibility of a segmental class, then this can be captured by faithfulness constraints. The perceptibility of retroflexes, for instance, can be ranked according to the cue availability in specific contexts, as illustrated in (4), where R stands for features specifying retroflexes (evidence for this constraint ordering, especially for the universally unusual ranking V_C >> C_V, will be given in section 3.5).

(4) *DELETE (R / V_V) >> *DELETE (R / V_C) >> *DELETE (R / C_V) >>
*DELETE (R / C_C)

The hierarchy in (4) incorporates the fact that retroflexes are least perceptible in interconsonantal context, and most perceptible in intervocalic context (see Steriade 1995 and 2002 for a similar approach). Such a hierarchy is applied in this dissertation to account for the phonotactic behaviour and the assimilatory behaviour of retroflexes.

The second type of perceptual markedness is restricted to the segments within a language inventory. This is illustrated by Padgett (2003: 5) with the case of palatalized and velarized consonants in Slavic languages. Both series are present for instance in Russian, but Russian does not employ the plain consonants without a secondary articulation. The presence of the plain series is predicted, however, by articulatory markedness: only if the plain articulation is present can secondary articulations (which are articulatorily more complex and thus marked) emerge as well. According to Padgett, the two secondary articulations in Russian are licensed since they are perceptually more distant than the plain articulation compared to one secondary articulated consonant. Phonologists working with this inventory-specific notion of perceptual markedness, such as Flemming (1995) and Padgett (2001, 2003), restrict their analyses to comparing segmental inventories with respect to one perceptual cue only. However, segments might be perceptually distant with respect to one cue, but perceptually very close with respect to another. For this reason and due to lack of sufficient data on the perceptual cues of inventories containing retroflexes, this notion of perceptual markedness is not pursued here.

A third notion of markedness is introduced by Bhat (1973: 55), who claims that retroflex segments are marked because they are introduced into a language through areal spread, through the assimilatory influence of neighbouring sounds such as back vowels, /r/ or, at a later stage, by other retroflex consonants. Bhat's observation only confirms the implication made earlier that retroflexes mostly occur in large segmental inventories, when other coronals are employed already. The areal spread of retroflexes provides further evidence for the observation that retroflexes do not have weak perceptual features, since languages are expected to borrow segments with strong perceptual features (compare for instance the areal spread of the click sounds in Bantu languages) rather than segments with weak features.

In sum, there is evidence that an articulatory basis for the cross-linguistic markedness of retroflexes exists. Furthermore, it was shown that retroflexes are not in general perceptually more marked than other segmental classes (for instance by having weak cues), but that their perceptibility is context-dependent. This context-dependent notion of markedness will be employed in the present dissertation to account for the phonological behaviour of retroflexes such as phonotactic restrictions and assimilation processes.

1.2 Phonetic cues and phonological features

One of the main questions in the present thesis is whether it is necessary and desirable to have one universal set of features for phonological representations (for retroflexes and for other classes), or whether language-specific features are more useful as they take into account other sounds in the respective languages and hence put emphasis on the distinctive function of features within a language (cf. Jakobson, Fant & Halle 1952). The assumption of a universal set of features in phonology stems from the aim to have only one, highly abstract set that can account for all languages. What is neglected by such abstraction is the fact that phonological rules often target phonetically very detailed cues in specific languages, as will be illustrated in chapters 4 and 6. This dilemma between abstraction and concrete detail, and the problem of drawing the borderline between phonological and phonetic knowledge is illustrated in the following citation by Ladefoged & Wu (1984: 277) on consonant classes:

> […] as phonologists, we will continue to describe the patterns among the contrasting sounds. As phoneticians, we will continue to describe the actual sounds that occur. Phonologists must behave as if there were distinct places of articulation, grouping sounds together in ways that are appropriate for the particular language being described. Meanwhile phoneticians will have to go on doing their best to specify the sounds of each language in general anatomical and acoustic terms. They will not be able to allocate consonants to a small number of cells on a chart […]. Languages divide up the continuum of possible places of articulation in different ways […]. There are, of course, favored regions that occur in many languages. But the phones that are grouped together phonologically in one language will not be the same as those that are grouped together in another. Nobody imagines that the vowel and tone spaces are divided into specific sets of categories. Why should we imagine that there *are* discrete places of articulation?

This quotation suggests that phonological representations should be abstracted away from the possible articulatory variation within a language. They should, however, not try to generalize across all languages to find one classification for all places of articulation. Such generalizations might be useful for very general cross-linguistic observations, but cannot be used as a tool for the phonological description of specific languages. I will assume a similar view of phonetic-phonological sound patterning here, in line with the general idea of functional approaches to phonology such as Boersma (1998) and Pierrehumbert (1999).

The resulting model of phonological knowledge as assumed in this thesis is represented in figure 1.1.

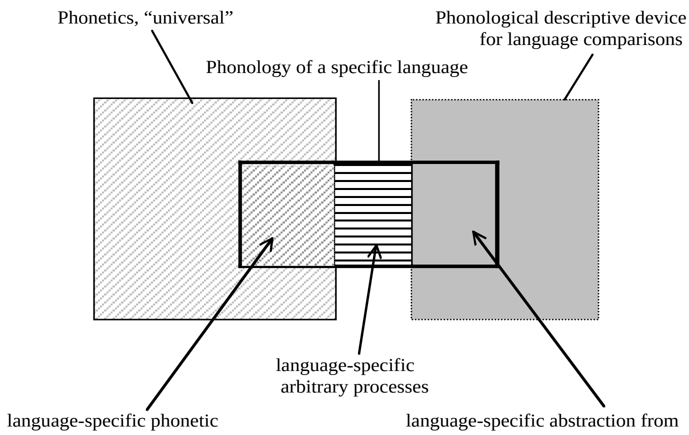

Figure 1.1 Model of phonological knowledge (the box outlined in bold in the middle) and its sources as assumed in the present dissertation.

In this figure, the left, light grey box represents the phonetics, which is based on the articulatory and acoustic apparatus of the human species and in this sense is universal. All of this phonetic knowledge is available to the language learner. From this, the learner chooses the cues that are relevant for the language-specific phonological processes (i.e., the smaller box within the grey box). To this phonetic knowledge relevant for phonology, the learner adds language-specific, arbitrary phonological knowledge, depicted as the striped box in the middle. Such knowledge includes processes that have to be specifically stored in the lexicon. Lastly, the phonology of a specific language also includes abstract phonological representations and processes, represented here as the small dark grey box on the right. This part of the phonology is an abstraction from the phonetic knowledge. The abstract, phonological knowledge partly overlaps with what linguists traditionally refer to as the innate Universal Grammar, the big grey box on the right. I propose that this so-called innate or universal module is only a descriptive device for language comparisons and yields an economic description of all languages. It is, however, not necessary to assume such an innate component since phonological knowledge can be acquired without it. In the present thesis it is assumed that cross-linguistic similarities of phonological segments and processes do not originate from a Universal Grammar but from their groundedness in the articulatory and perceptual apparatus and the categorizing mechanisms of the human, in line with functional approaches to phonology such as Nathan (1994), Pierrehumbert (1994), and Boersma (1998).

In general, the model in figure 1.1 represents the phonological knowledge of a speaker, its dependence on phonetics, and its interrelation with what is traditionally termed UG. It is, however, not meant to give a full-fledged model of phonology and phonetics or other grammatical modules. In addition to this phonological component, the speaker is assumed to have, amongst others, a component including phonetic knowledge that is not relevant for phonological processes but necessary for the realization of segments, a lexical component, and so on.

1.3 Outline of the dissertation

The dissertation is divided into two sections, a phonetic one and a phonological one. The first section, which subsumes chapters 2 and 3, is concerned with the *phonetic* definition of retroflexion. In chapter 2, several articulatory parameters responsible for the large variation of this class are described, and four prototypical properties for retroflexion are proposed. Chapter 3 provides acoustic definitions of retroflexion and two cues that hold for all retroflex segments. In terms of the model given in figure 1.1, chapters 2 and 3 set the possible space for retroflex articulations and perceptual cues within the general phonetics space, from which languages with a retroflex class pick their actual realizations. This retroflex space is depicted schematically in figure 1.2 within the model as introduced in figure 1.1.

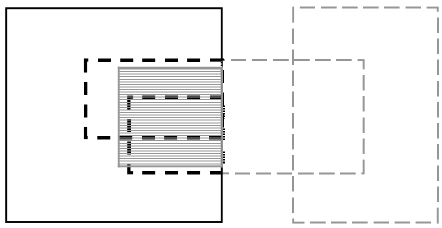

Figure 1.2 Schema of the part of the model that is discussed in *chapters 2 and 3*. The small grey box indicates the possible retroflex articulations (within the phonetics space), from which languages choose their exact realizations. The boxes with dashed outlines illustrate two language-specific choices from the phonetic space (including all non-retroflexes).

In figure 1.2 and the following figures, the part of the model that is dealt with in the respective chapters is highlighted either by grey hatching or by bold lines.

The second section, chapters 4 - 6, deals with the *phonology* of retroflex segments. The fourth chapter is concerned with phonological processes involving retroflex segments that can be found in many languages with this segment class. Furthermore, chapter 4 illustrates the phonetic grounding of these processes, but also to what extent the processes are idiosyncratic and not phonetically motivated. In my model, this can be depicted as in figure 1.3.

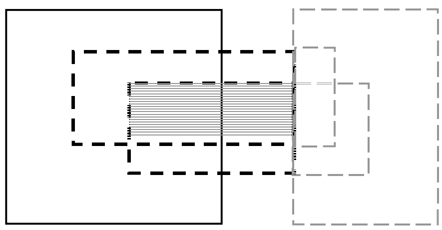

Figure 1.3 Topic of *chapter 4*: Phonological processes involving retroflexes and their phonetic grounding. Here depicted by the phonology of two possible languages (excluding the abstract part in the right box) and their overlap with respect to retroflexion.

In chapter 5, I discuss previous phonological representations of retroflexes that primarily focused on the search for universal representations and thus mainly ignored language-specific, phonetic details. In this respect, chapter 5 deals with the right box in our model, the supposedly “universal” knowledge. This chapter also includes newer proposals for representations that refer to phonetic (especially perceptual) details.

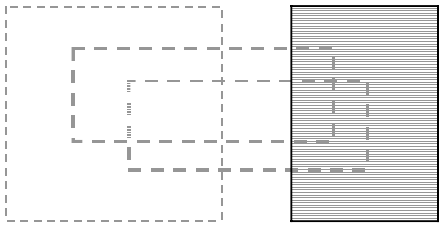

Figure 1.4 Phonological representations as topic of *chapter 5*. These include both approaches that refer to universal feature sets, and others that use only language-specific features.

In chapter 6, I propose phonological representations of retroflex-specific processes, based on the phonetic details chosen by particular languages. These representations partially describe and account for the variation between languages with respect to specific processes. This variation, and the cross-linguistical commonness of a specific variant versus the rare occurrence of another variant, is accounted for by the universality of the phonetic apparatus. Chapter 6 thus deals with the whole phonological knowledge of several languages as depicted with the central boxes in figure 1.5.

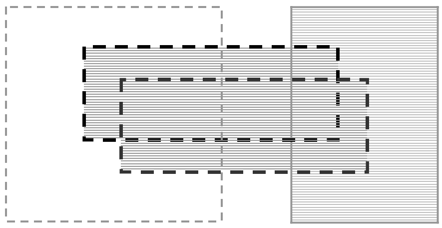

Figure 1.5 Topic of *chapter 6* are language-specific and universal phonological features that can account for the phonological processes of retroflexes (topic of chapter 4). Again, two sample phonologies of specific languages are depicted.

Chapter 7 concludes and points out advantages and shortcomings of the present dissertation. Furthermore, it gives an overview of topics that could not be dealt with here and are open to future research.

2 Articulatory variation and common properties of retroflexes

Retroflexion is traditionally described as an articulation involving the bending backwards of the tongue tip, see for instance the definition by Trask (1996: 308). An illustration of such a retroflex is given in figure 2.1, based on a sagittal x-ray tracing of a Tamil retroflex stop from Ladefoged & Maddieson (1996: 27).

Figure 2.1 Tracing of a sagittal x-ray of a retroflex stop in Tamil, based on Ladefoged & Maddieson (1996: 27). This articulation is a retroflex in the traditional sense with the tongue tip bent backwards and having contact on the post-alveolar area.

The Latin-based term 'retroflex' (Dixit 1990), bending backwards, refers to a tongue gesture as depicted in figure 2.1.

In the present chapter it will be shown that the class of retroflexes displays large articulatory variation, and that the actual gesture of bending the tongue tip backwards is not a defining property of this class because it is not true for all sounds traditionally described as retroflex. This chapter investigates the articulatory variation of retroflexes and the factors responsible for variation, and proposes a different articulatory definition of retroflexion, namely by the four properties of *apicality*, *posteriority*, *sublingual cavity*, and *retraction*. Bending backwards of the tongue tip is not included in these four properties. It will be shown that most of the segments traditionally described as retroflex satisfy all four properties. One noticable exception to this is the retroflex fricative in Mandarin, that lacks the property of posteriority. Furthermore, the four properties introduced here will be shown to imply that secondary palatalization of retroflexion causes a change from retroflex to non-retroflex, as the palatalized segment satisfies only two retroflex properties.

This chapter proceeds as follows. In section 2.1, the phonetic terminology to be used is defined. Section 2.2 is concerned with both the phonetic and phonological factors responsible for the large articulatory variation in retroflexion. This includes descriptions of the manners of articulation that retroflexion can occur with. Abstracting away from the described variation, section 2.3 describes in detail the four properties that characterize retroflexion; apicality, posteriority, sublingual cavity, and retraction. In section 2.4, these properties are applied to post-alveolar fricatives of Slavic languages which are treated in the traditional literature as laminal but which are argued here to be retroflex. The subsection illustrates that these Slavic segments can be considered as non-prototypical retroflex fricatives since they satisfy three of the four properties postulated in 2.3. Section 2.4 concludes that the property of posteriority is the only one that can be missing for such non-prototypical retroflex fricatives. Section 2.5 is concerned with the secondary palatalization of retroflexes. There it is argued that secondary palatalization causes a change from retroflex to palato-alveolar. The last section 2.6 summarizes.

2.1 Phonetic terminology

In this dissertation, several articulatory terms are used. To avoid confusion, short definitions of these terms are provided here. First of all, a distinction between active and passive articulator is made. The active articulator is either the lower lips or some part of the tongue. This active articulator (sometimes just referred to as 'articulator' in the phonetic literature) moves towards the immobile, passive articulator, which is the area on the upper side of the vocal tract from the upper lips to the pharynx. The passive articulator is also referred to as 'place of articulation' in most phonetic studies.

For the present study, two specific regions of the active and the passive articulator are of importance. In the case of the active articulator this is the front part of the tongue, which is usually divided into tongue tip and tongue blade. This area is often referred to as 'coronal' in the phonetic and phonological literature. Sounds produced with the tongue tip are called apical, those with the tongue blade laminal. There are two differing views on where the borderline between tip and blade is located. According to the traditional view, as represented e.g. by Catford (1988, 1994) and Ladefoged & Maddieson (1996), the tip is the part of the tongue that is roughly vertical at rest, and the tongue blade starts just a few millimetres after this vertical part, see figure 2.2 below. A different view is represented by e.g. Ohde & Sharf (1992), who count both tip and blade as defined above under the term 'tongue tip' and use 'blade' for the front area of what is traditionally referred to as the tongue dorsum. The present study follows the traditional definition of tongue tip and blade.

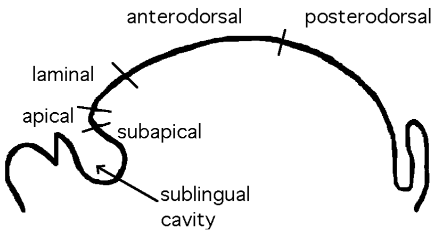

Figure 2.2 Representation of the sublingual cavity and of the parts of the tongue (based on Catford 1988).

The underside of the tongue, i.e. the area below the tongue tip, can be referred to as subapical (e.g. Catford 1977 and Laver 1994), or sublaminal (e.g. Ladefoged & Maddieson 1996 and Dixit 1990). In the present study, the term 'subapical' will be used. The space between the tongue tip and the lower teeth that comes into existence when the tongue tip or blade is raised towards the post-alveolar region or further back is called the 'sublingual cavity'.

Behind the laminal area, which extends 1 to 1.5 cm behind the apex, the tongue dorsum starts. The tongue dorsum is sometimes referred to as tongue body and can be further distinguished into pre-dorsum and post-dorsum, or anterodorsum and posterodorsum (e.g. by Catford 1988), the latter often called the tongue back. According to Catford (1988: 79) this distinction of the dorsum is not necessary, since the anterodorsum practically always articulates against the roof of the mouth in the palatal area, and the posterodorsum articulates in the velar area. In the present study I will refer to these two parts of the dorsum as tongue middle and tongue back, respectively.

For the passive articulator, the focus of the present study will be on the area on or behind the alveolar ridge. The alveolar ridge is the protuberance immediately behind the upper teeth, after which a concave slope of the palate starts (cf. for instance to the definition by Catford 1977). The alveolar ridge can be seen in figure 2.3 in the alveolar area:

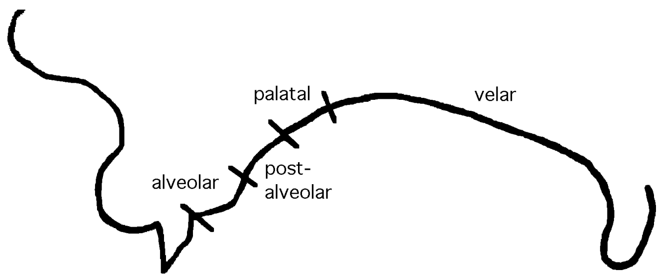

Figure 2.3 Representation of the alveolar, post-alveolar, alveolo-palatal, palatal, and velar regions (based on figures by Heike 1982: 26 and Laver 1994).

Articulations on the alveolar ridge are called 'alveolar'; those right behind the ridge are 'post-alveolar'. Behind the short stretch of the post-alveolar region, the palatal area is located. The remainder of the palate is the 'velar' area.

Besides these distinctions of active and passive articulators, some terms for specific sound classes have to be defined explicitly since they will be used throughout the dissertation. First of all, I will use the term 'apical alveolar' for all front apical articulations, including apical dentals. The anterior apical is realized language-dependently, but the realization of an apical alveolar is cross-linguistically more common (Ladefoged & Maddieson 1996: 23), therefore this term is used here. Apical alveolars are transcribed with the IPA symbols [t, d, n, l, s, z, r] without further diacritics. Laminal dentals or alveolars are transcribed with a dental diacritic, for instance [t̺], since they are dental in most languages. Laminal post-alveolars are transcribed as [t̠] etc.

Laminal fricatives articulated in the post-alveolar region, transcribed with the IPA symbols [ʃ, ʒ], will be termed ‘palato-alveolar’ (following e.g. Trask 1996: 255). Together with the retroflexes they make up the class of ‘post-alveolar’ fricatives. Laminal fricatives articulated with a narrow constriction at the post-alveolar and the palatal area, i.e. [ɕ, ʑ], are referred to as ‘alveolo-palatal’ fricatives (e.g., by Trask 1996).

Regarding the tongue shape, the terms ‘domed’ and ‘flat’ will be used in the present dissertation. ‘Domed’ describes a raised tongue middle as can be found in articulations of the palato-alveolar [ʃ, ʒ], or in any kind of secondarily palatalized coronals. ‘Flat’ can be used in two different meanings, one indicating the non-raising of the tongue middle towards the palate, i. e. flatness in the sagittal dimension: in the present study the term will be used in this meaning. The second meaning is applied e.g. by Laver (1994: 252) who uses ‘flat’ to refer to a fricative that lacks a groove in the tongue middle, i.e. flatness refers here to the cross-sectional dimension of the tongue.

2.2 Parameters of articulatory variation

In contrast to other articulatory classes (such as e.g. dentals) that have a fixed place of articulation and active articulator and therefore allow little variation, retroflexes have a wide range of articulatory possibilities, which will be examined in this section. The indeterminacy of the retroflex class is reflected by the fact that the IPA symbol chart lists ‘retroflex’ along with terms referring to places of articulation such as ‘dental’, ‘alveolar’ etc., although I argue below that ‘retroflex’ describes an articulatory shape or gesture, rather than a place of articulation. Ladefoged (1975) nevertheless uses ‘retroflex’ in his phonetic feature systems as a value of the feature ‘articulatory place’. A similar use of this term can be found in Maddieson (1984). Catford (1977), Ohala (1983), and Laver (1994), on the other hand, apply the term ‘retroflex’ exclusively to the articulatory gesture.

Besides the cover term ‘retroflex’, one can find several more accurate descriptions of retroflex segments in the phonetic literature; terms used for the active articulator are e.g. ‘apical’, ‘subapical’ or ‘sublaminal’; terms for the passive articulator are ‘alveolar’, ‘post-alveolar’, ‘prepalatal’ or ‘palatal’. Nevertheless, ‘retroflex’ behaves parallel to true places of articulation because it has the same manner of articulation classes, i.e. plosives, fricatives, nasals, and so on.

The difficulty in describing the articulation of retroflexes is due to several parameters of variation, some of which are purely phonetic, such as speaker dependency, dependency on the manner of articulation, or the segmental context of the retroflex. Others are phonological, such as the inventory size of a language or common characteristics of the language family.

In this section, the main parameters of variation are described, starting with the phonetically motivated intra-speaker variation in 2.2.1. Three further phonetic sources for variation are subsequently introduced, namely the vowel context of the segments (2.2.2), speech rate (2.2.3), and manner of articulation (2.2.4). In sections 2.2.5 and 2.2.6, two phonological parameters, namely language family and inventory size, are described respectively. Mutual influence of the factors on each other occurs, as will be illustrated when appropriate.

2.2.1 Speaker dependency

The shape of the tongue and the exact placement of the tongue tip depend very much on the speaker's vocal tract. There is large variation between speakers in their vocal tract anatomy and in their flexibility of the articulators. Concerning the place of articulation for retroflexes, Catford (1970: 310) points out that "some people can curl up their tongue retroflexively so that the tongue-point touches the uvula: others can barely reach the centre of the hard palate". An apical uvular (i.e. a retroflex in the uvular region) is therefore theoretically possible for some speakers, but no language seems to employ this sound.

The active articulator for retroflexes is also subject to speaker variability; it can vary from the tongue tip or blade to the extreme underside of the blade.

Phonetic investigations of the realization of retroflex segments within one language confirm intra-speaker variation. Ladefoged & Bhaskararao (1983) made x-ray tracings of Hindi voiceless retroflex stops for five native speakers. Whereas four of the speakers have an alveolar place of articulation (varying between apical and subapical articulator), the fifth shows a subapical post-alveolar articulation. An electropalatographic (henceforth: EPG) and electromagnetographic study of Norwegian retroflex stops by Simonsen et al. (2000) for two native speakers showed similar variation between the speakers; one articulates the retroflex with a bent tongue tip and a post-alveolar contact, the other without bending and with an alveolar contact. That variation depending on the speaker is consistent across different manners can be seen in Dart & Nihalani's (1999) experiment for Malayalam. Their palatographic and linguographic data of nine speakers show that eight speakers produce post-alveolar retroflex stops, and one an alveolar one. The same speaker also shows an alveolar place of the retroflex nasal, whereas all others have a post-alveolar nasal. The consistency of the single speaker's articulation across different manners was also observable for the active articulator.

The degree of variation open to the speaker can be limited by the inventory size of the language, as will be shown in section 2.2.5. But even for Australian languages that employ a four-way place distinction in the coronal area (such as for instance Eastern Arrernte, Miriwung, and Wembawemba), and where one therefore would expect nearly no variation, Hamilton (1996: 37) observes that the articulation of retroflexes is less uniform than that of the alveolars, and furthermore that the area of contact for retroflex segments is much broader.

Variation due to a speaker's gender should also be mentioned in the context of speaker-specific differences in articulation. The vocal folds are usually longer for men than for women, and vocal fold vibration is therefore lower for men (Beck 1997). Furthermore, the vocal tract is generally larger for men, which results in lower formant values. However, this is a general phenomenon not restricted to retroflex segments and has therefore not been the topic of any articulatory study on retroflexion.

2.2.2 Vowel context

Vowel context seems to be one of the major causes for variability in retroflexion. Several studies such as Švarný & Zvelebil (1955), Ladefoged & Bhaskararao (1983), Dixit (1990), Dixit & Flege (1991), and Krull, Lindblom, Shia & Fruchter (1995) illustrate the change of the active articulator and the place of articulation of retroflex segments according to the adjacent vowel. Dixit (1990) and Dixit & Flege (1991) for instance made EPG measurements of the retroflex stops [ʈ] in Hindi preceded and followed by the vowels [a u i]. The results of both studies show that the place of retroflex constriction changes according to the vowels. In /i/ context, i.e. preceded and followed by an /i/, the retroflexes were articulated in the dental area, in /a/ context in the alveolar region, and in /u/ context in the post-alveolar area. Similar results were obtained by Simonsen et al.'s (2000) EPG experiments with two native speakers of Norwegian, where the retroflex in the /a/ vowel context was articulated far more back than in the /i/ context. Variance in retroflexion according to vowel context is obviously a coarticulatory effect and can be explained physiologically. For the front vowel /i/ the tongue blade is fronted and the tongue middle raised, and the tongue tip is usually tucked under the lower front teeth. This tongue shape is inherently less compatible with that of retroflexion than e.g. a neutral tongue position, and therefore the combination of both front vowel and retroflex gesture results in the reduction of either the degree of retroflexion or the frontness of the vowel. For both processes see the phonological rules of de-retroflexion in high front vowel context, high vowel lowering, and front vowel retraction, all described in section 4.3. The articulatory gesture for the low vowel /a/ has neither a fronted tongue blade nor a raised tongue middle, thus it allows a posterior retroflex articulation. The high back vowel /u/ is articulated with a raised and retracted tongue back, a position very similar to that of the retroflex. The tip is not constrained in this type of articulation and can move easily to or from the retroflex gesture.

The position of the vowel with respect to the retroflex has a considerable influence on the variation of retroflexes. The quality of the preceding vowel has a different effect on retroflexion than that of the following one. In Simonsen et al.'s (2000) study on Norwegian retroflex stops, the contact on the palate was further back in post-vocalic position than in prevocalic position, both for /i/ and /a/ context. Krull et al. (1995) have similar results in their study of Swedish, Hindi, and Tamil retroflexes. The difference between post-vocalic and pre-vocalic position is that during the preceding vowel the tongue tip advances into the post-alveolar region. The retroflex consonant itself involves a movement of the tongue tip from this post-alveolar displacement to its natural resting position or to the position necessary for the following vowel. This is sometimes referred to as 'flapping out', see e.g. Ladefoged (1964) on West African rhotic retroflexes or Hamilton (1996: 37) on Australian retroflex segments. The movement from the retroflex gesture towards neutral tongue position or tongue position of the following segment during the production of the consonant is very pronounced for retroflex stops and nasals (illustrated e.g. in Butcher's 1992 palatography of retroflex stops in Australian languages). Retroflex fricatives differ slightly, as they usually hold the posterior tongue position during almost all of the frication and only show a very late flapping out.[1] But in judging these differences one has to take into account that fricatives usually show less bending backwards of the tongue tip than stops, see section 2.2.4.3 below. The articulatory influence of the vowel preceding a retroflex segment is thus far greater than that of the following vowel, and more vowel-dependent variation can be observed in post-vocalic retroflexes than in pre-vocalic ones. This dependency on position of the vowel is again unique to retroflexion. Dentals do not show any variation across post- and pre-vocalic position, as illustrated by Krull et al.'s (1995) study on Swedish and Hindi, and Simonsen et al.'s (2000) study on Norwegian.

2.2.3 Speech rate

Speech rate is another factor influencing the articulation of retroflex segments. Bhat (1974b: 236) states in his cross-linguistic study that the bending backwards of the tongue tip decreases with the speed of the utterance. This is in accordance with Ladefoged & Maddieson's (1996: 222) finding that some speakers of Malayalam have a contrast between alveolar and retroflex trill in careful speech only. Dixit & Flege (1991) tested in an EPG experiment the influence of speech rate on retroflex articulations of the Hindi stop [ʈ]. Their results show that in fast speech the constriction for the retroflex is more posterior. No information was provided about the reduction of the tongue tip gesture. The retraction of the place of articulation seems to go counter expectations, because one would suppose a reduction of the retroflex gesture to result in a position closer to the neutral position of the tongue tip. Dixit & Flege (1991) explain their findings in the following way:

> [T]he place of tongue-palate contact receded in fast speech probably because the general shape of the tongue was more like its bunched shape in the surrounding vowel. Therefore the tongue tip or blade did not reach the same articulatory place in fast speech as it did in normal or loud speech. (Dixit & Flege, 1991: 223)

Dixit & Flege hence propose that the bunched tongue body shape of the vowel influences the tongue shape of the retroflex in fast speech, which results in a more posterior place of articulation for the retroflex stop. Alternatively, the retraction of the tongue body might be interpreted as a compensatory gesture: the fast speech rate does not allow a raising and retraction of the tongue tip, thus the speaker retracts the whole tongue body (which can be done during the vowel artiuclation already) and then only has to raise the tongue tip.

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[1] The difference between retroflex fricatives and stops with respect to the occurrence of the 'flapping out' is not the subject of any articulatory study to my knowledge. It can also be inferred from the transitions in the acoustic signals, see chapter 3.

Lindblad & Lundqvist (1997) looked at Swedish coronal fricatives in isolated vs. phrasal production (which I assume to be equivalent to slow vs. fast speech). Their results show a more fronted articulation of the retroflex fricative in phrasal, fast speech; i.e. a change from a post-alveolar/palatal place of articulation in isolated speech to an alveolar place in fast speech. Both studies only looked at a change in the place of articulation, not at the tongue tip. Whether the tongue tip gesture is reduced in fast speech has to be further tested. Furthermore, it cannot be established whether the differing results for Hindi and Swedish are language-specific (Hindi has retroflex retraction in fast speech whereas Swedish has fronting) or manner-specific (fricatives are fronted whereas stops are retracted). Further studies have to be conducted to clarify this point.

2.2.4 Manner dependency

The third and most important phonetic parameter for variation of retroflex sounds is the manner of articulation. As we will see in the following, there are some systematic differences between retroflex manners. This difference is not restricted to retroflexes but is a general articulatory necessity. Lindblad & Lundqvist (1999: 417) observe in their study on front coronal sounds that “the hypothesis that sounds that share roughly the same articulatory gesture nevertheless tend to differ in gestural details, caused by general production conditions for each specific articulatory manner, is certainly valid also for all other sounds, not least posterior coronals such as retroflex sounds.” To exemplify this in detail, the following sections will examine the retroflex articulations of plosives, fricatives, affricates, laterals, and rhotics respectively. Manners articulated with ingressive airstream, such as implosives and clicks, and with glottalic egressive airstream (ejectives) are not discussed.

Before describing the manners of articulation for retroflexes, it has to be pointed out that retroflexes also occur as geminates, as in Bengali, Marathi, and Tamil. As geminates can occur with all of the manners described below, they are treated briefly here. Balasubramanian (1982) investigated the articulatory difference between singleton and geminate nasal and lateral retroflex in Tamil and his study shows that retroflex geminates, which occur intervocalically only, are articulated with a firmer contact than the non-geminated counterparts. The nasal retroflex geminates are also articulated further back than the singleton nasals, namely in the palatal region. Thus, the realization as singleton or geminate can account already for some articulatory variation of retroflexes.

2.2.4.1 Plosives

In the phonetic and phonological literature one often finds the distinction between two kinds of retroflex stops. Keating (1991: 34f.) and Hall (1997: 46) for example describe an apical and a subapical post-alveolar retroflex segment, where the second involves a more retroflex gesture than the first.[2] Figure 2.4 exemplifies these two

[2] Keating (1991) and Hall (1997) do not refer to stops specifically, but their articulatory illustrations for both types of retroflex articulations are taken from stops only.

stop types, with a retroflex stop from Hindi on the left, and one from Tamil on the right.

Figure 2.4 Hindi retroflex stop [ɖ] (left) and a Tamil retroflex stop [ɖ] (right), both based on sagittal x-ray tracings from Ladefoged & Maddieson (1996: 27).

The Hindi retroflex stop is articulated with the tongue tip against the post-alveolar region, whereas the Tamil retroflex stop involves a placement of the underside of the tongue tip against the palatal region. Whereas Hall (1997) assumes that there are only these two retroflex articulations, Ladefoged & Bhaskararao (1983) point out that the two types like the ones illustrated here can be assumed to be extremes on a continuum of possible retroflex plosives.[3] Taking into account all the other parameters of variation described up to now and the changes in articulation they incur, the view of retroflex articulation as a continuum seems appropriate. But in order to avoid mentioning all possible articulations of retroflex stops, the following will be mainly concerned with the description of the two extreme types.

In order to distinguish phonetically between these two extreme articulations of retroflex stops, Ladefoged & Maddieson (1996: 15) introduce two different symbols. The type found in Hindi, involving just the tongue tip (see figure 2.4 left), is transcribed with a subscript dot beneath the symbol for the alveolar sound [ṭ] whereas the articulation with the underside of the tongue (see figure 2.4 right) as in Tamil and other Dravidian languages is transcribed with the traditional IPA symbol for retroflex stop [ʈ]. Švarný & Zvelebil (1955) also distinguish the two types, and introduce a different term for each. In their terminology, 'retroflex' stops involve the use of the underside of the tongue, whereas 'cacuminal' stops use the tongue tip only.[4] Ball & Rahilly (1999: 56) propose the use of the IPA diacritics for 'advanced' and 'retracted' to differentiate between the two retroflex places of articulation. Sections 2.2.5 and 2.2.6 below look at the correlation between the two retroflex types in figure 2.4 with the language families they occur in, and their co-occurrence with other coronal segments within one language, respectively.

Usually, the voiced and voiceless retroflex segments in one language are articulated at the same place. However, Ladefoged (1964) observed that some West

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3 Ladefoged & Maddieson (1996: 26) assume that the retroflex voiced stop in Ewe (a West-African language) is even less retroflexed than the Hindi one, being articulated actually at the alveolar ridge, and therefore should be one endpoint of the continuum. Their palatographic data, however, show that the tongue moved from the post-alveolar to the alveolar area during articulation, which makes its place of articulation very similar if not identical to that of the Hindi stop.

4 Dixit (1990: 190) points out that 'cacuminal' is a term referring to the place of articulation rather than to the tongue gesture, though Švarný & Zvelebil use both 'retroflex' and 'cacuminal' for describing the active articulator.

African languages (Ghanaian languages such as Gã, Effutu, Late and Anum) have a difference in place of articulation between the voiceless and the voiced coronals. Whereas the voiceless stop is laminal denti-alveolar, the voiced one is apical alveolar or post-alveolar, i.e. retroflex. No possible reasons for this difference are given. The only further evidence for a difference between the voiced and voiceless series could be found in Dixit's (1990) measurements of Hindi, which showed that the voiced retroflex (and dental) have narrower constrictions than the voiceless counterparts. But no change in place of articulation resulted from that.

Retroflex stops have in common that they involve a flapping out of the tongue tip in their articulation. This gestural release takes place at the release of the stop.[5] In Ladefoged's (1964) investigations of Ewe stops, the tongue tip movement during the release is observable from a large area of contact at the roof of the mouth, though the active articulator was actually quite small. Further unifying properties for both retroflex stop types and also of the following manners will be discussed in 2.3.

2.2.4.2 Nasals

Coronal nasals are often produced at the same place of articulation and with the same articulator as the corresponding stops in the respective languages. Maddieson (1986) observes that the presence of a nasal usually implies the presence of a plosive or obstruent at the same place of articulation. This is attested in Dart's study (1991) on the articulatory similarity between coronal stops and coronal nasals in French and in English.[6]

For retroflexes, Laver (1994: 217) shows with sagittal cross-sections that the retroflex stops and nasals in Tamil have identical active and passive articulators and the same gesture of articulation.

Further evidence for a similar treatment of retroflex nasals and stops can be drawn from the fact that languages which employ a retroflex nasal also have a retroflex stop. The only counterexample in Maddieson's database is the Finno-Ugric language Ostyak, which has a retroflex affricate and a retroflex lateral as the only other retroflex segments besides the retroflex nasal.

Butcher (1992: 25) claims that in Australian languages stops appear to be more likely to have sublaminal articulation than nasals, thus implies a difference in active articulator between retroflex nasals and stops. However, Butcher does not give any phonetic evidence for his claim.

Only a few articulatory studies, such as Balasubramanian (1982) and Dart & Nihalani (1999), are concerned with nasal retroflexes. Dart & Nihalani (1999) investigated the coronal nasals and stops of Malayalam. For all nine speakers of their study the nasal retroflex was articulated at the same place and with the same articulator as the stop, namely subapical for six speakers, apical for three, with a post-alveolar place for all except one, who had an alveolar place. Balasubramanian

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5 This observation holds only for released retroflexes. Unreleased retroflex segments such as e.g. [ʈ̚] do not show any flapping out. Unreleased [ʈ̚] occur for example before other coronal consonants, before retroflexes with a different manner of articulation, or phrase-finally in some languages.

6 See e.g. Boersma (1998: 162f.) on how specific articulatory gestures are used for more than one manner class and how this can account for symmetries within segment inventories.

(1982b) looked at retroflex nasal singletons and geminates in Tamil of one speaker, who produced a subapical post-alveolar for the singleton and a subapical palatal for the geminate. As these studies were concerned with retroflex nasals in Dravidian languages, they give descriptions of subapical post-alveolar articulations only. But assuming that the nasal is articulated in the same way as the corresponding stop in the respective languages, there should be a more apical retroflex nasal e.g. in Indo-Aryan languages. As we do not have any further data to refute the claim, we thus assume that nasals can vary articulatorily in the same way as retroflex stops do.

2.2.4.3 Fricatives

The articulatory requirements for fricatives are different from those for stops and nasals. The front coronal fricative [s], for example, seems to be cross-linguistically more laminal than the corresponding stop [t] (see for instance Dart 1991 on French and English, Lindblad & Lundqvist 1999 on Swedish, and Wängler 1958 on German). This is due to the fact that strident coronal fricatives require a grooving of the tongue blade and an air-jet that strikes the front incisors (Lindblad & Lundqvist 1999), which can be easier achieved with a longer place of constriction. Thus one would expect retroflex fricatives to differ inherently from the articulatory configuration found in retroflex stops or nasals, as the contact area of retroflex stops is rather small. Furthermore, one can speculate that retroflex fricatives require the retroflexion gesture to be held throughout the whole segment in order to maintain the air turbulence, whereas stops allow an early flapping out (recall the description in 2.2.4.1). Keating (1991: 35) confirms these expectations of a different articulatory position for fricatives by pointing out that retroflex fricatives of India do not seem to involve the same kind of curling of the tongue as the plosives in these languages, but are articulated at the same place as the plosives.

Let us look at some realizations of retroflex fricatives in order to test the assumptions made up to now. The left hand side of figure 2.5 on the next page is a sagittal x-ray tracing of the Tamil retroflex fricative (Ladefoged & Maddieson 1996: 156). In this picture, the tongue tip is not distinguishable from the tongue body; therefore no raising or bending backwards of it is discernible. Compared to the retroflex stop in the same language (refer back to figure 2.4), the fricative differs very much in its articulation and shows a longer, narrower channel of articulation.[7] Thus, the retroflex fricative type found in Tamil is in accordance with the assumptions made above.

According to the detailed phonetic descriptions of Sridhar (1990), a similar difference between the retroflex plosive and the retroflex fricative can be found in Kannada, another Dravidian language. Toda, though from the same language family (Dravidian) as Tamil and Kannada, and having the same type of retroflex stop, shows a different articulation of the retroflex fricative, depicted in figure 2.5 on the right (based on Ladefoged & Maddieson 1996: 160).

[7] The x-ray tracing of the Tamil fricative in figure 2.5 shows no discernible tongue tip, which seems to be retracted into the tongue.

Figure 2.5 Tamil retroflex fricative [ʂ] (left) and a Toda retroflex fricative [ʂ] (right).

The Toda retroflex fricative involves a raising of the tongue tip towards the palatal region, and its position of the tongue blade against the post-alveolar region resembles the articulation of the retroflex stop in Indo-Aryan languages. The articulation of the Toda fricative, which is further backwards than that of the Tamil fricative, still does not involve the extreme curling backwards of the tongue tip found in Dravidian retroflex stops. Ladefoged & Maddieson (1996: 156) introduce again two different symbols for the two retroflex fricative articulations. Whereas the Tamil-type of fricative is transcribed with an alveolar symbol with a subscript dot [ṣ] and is called a ‘flat retroflex’ (defined as not being domed like palato-alveolars), the fricative found in Toda is transcribed with the traditional IPA symbol for retroflex fricatives, namely [ʂ].

A retroflex fricative with an extreme curling backwards of the tongue tip, comparable to the Tamil stop in figure 4.1 on the right, could not be found in any articulatory study. Laver (1994: 252) mentions a subapical palato-alveolar fricative as a possible retroflex articulation but does not refer to any language that employs a segment like this. From this we can conclude that retroflex fricatives do not involve the same backwards bending of the tongue tip as retroflex stops, which probably has to do with the different articulatory requirements on fricatives elaborated above.

Besides the generally accepted two types of retroflex articulation exemplified up to now, another type of retroflex fricative exists. This type does not necessarily involve the tongue tip in its articulation and thus shows no kind of bending backwards of the tip at all. Its place of constriction is the post-alveolar region (recall the definition in section 2.1), but it differs from the traditional laminal post-alveolar [ʃ] and from the retroflex fricative in figure 2.5 left in the shape of its tongue body, which is flatter. Fricatives like these can be found in Mandarin Chinese, see figure 2.6 (based on Ladefoged & Wu 1984: 269).

Figure 2.6 X-ray tracing of the Mandarin voiceless retroflex fricative (based on Ladefoged & Wu 1984: 269).

In the traditional phonetic literature, the Mandarin sounds of voiced and voiceless post-alveolars are referred to as 'retroflex' (e.g. Chao 1948, 1968). Phonological descriptions agree with this terminology, cf. Chao (1986), Pulleyblank (1989), and Lin (1989). Laver (1994: 252), however, describes 'Standard Chinese' as having a laminal 'flat' post-alveolar fricative, 'flat' as this sound does not show any grooving of the tongue blade otherwise typical for coronal (including retroflex) sibilants, and he introduces the symbol [$ʃ_+$] for this segment. Ladefoged & Wu (1984: 277) point out that the Mandarin retroflex is very different from the same segment class in Tamil. The study by Lee (1999) with palatograms and linguograms shows that these sounds are apical post-alveolars for the two speakers tested. These findings lead Lee to refrain from referring to this segmental class as 'retroflex', since it shows no bending backwards of the tongue tip. The present study follows traditional phonetic literature and Ladefoged & Maddieson (1996) in classifying these sounds as retroflex.

Some Slavic languages, such as Polish and Russian, are said to have similar fricatives, though in the traditional Slavic literature they are never described as 'retroflex' (e.g. Wierzchowska 1980 and Rubach 1984). Articulatory arguments for why these sounds are classified as retroflex in the present study are discussed in detail in 2.4, phonological reasons are given in chapter 4.

2.2.4.4 Affricates

In the following discussion of retroflex affricates, four types of affricates are distinguished: first, a segment that is traditionally described as affricate, i.e. a stop that is released into a homorganic fricative, second, a stop that is released into a rhotic, thirdly, a laterally released stop, and lastly, a nasally released retroflex stop.

The retroflex affricate [ʈʂ][8] can be found e.g. in Burushaski (Edelman 1983), Gujarati (Pandit 1954), Karok (Bright 1957), and Mandarin (Ladefoged & Wu 1984), which all also have a retroflex fricative.[9] As can be seen in many articulatory descriptions of specific languages (e.g. Ladefoged 1994 on Toda and Ohala 1994 on Hindi), affricates differ in place of articulation from the corresponding stops, in as far as they are usually more retracted, and are close to the series of corresponding fricatives.[10] The retroflex affricates in Polish and other languages are therefore assumed to be identical in place and degree of articulation to the retroflex fricatives described in 2.2.4.3 and to show similar variation.

The second type of affricate to be treated here are the rhotically released stops, which can be represented with the symbols [ʈɽ] or [ɖɽ]. They occur in Athapaskan

[8] This segmental class is also transcribed as [tʂ]. The exact place of articulation of the plosive part is not further investigated in any study of my knowledge, therefore no decision on the correct transcription can be made here. In the present dissertation, the stop is assumed to be homorganic with the fricative part.

[9] From the seven languages with a retroflex affricate listed in Maddieson (1986), Ostyak and Jaqaru do not have a retroflex fricative in their inventory. Furthermore, the Micronesian language Ponapean has an affricate and a flap as its only retroflex segments (Rehg 1973). From this follows that a retroflex affricate does not imply the presence of a retroflex fricative in the same language.

[10] Kehrein (2002: 7) observes that strident affricates (as opposed to laterally or nasally released affricates) form phonologically a class with the corresponding fricatives.

languages such as Minto-Nenana (Tuttle 1998) and Upper Kuskokwim (Krauss 1973: 906), and in the Australian language Anguthimri (Crowley 1981: 152). Rhotically-released stops are usually not included in phonetic descriptions of possible affricate articulations. In traditional Athapaskan literature (e.g. Kraus 1979), these segments are however referred to as affricates because they show the same three-way phonation contrast of plain, aspirated and glottalized phonemes as other Athapaskan affricates such as e.g. [ts]. This classification seems worth following.

According to Crowley (1981: 152), the Anguthimri affricates, which he symbolizes as [tʳ, dʳ], are post-alveolar stops articulated slightly behind the alveolar ridge and followed by a trill. Phonotactically, they behave like one segment. Crowley notes that these sounds are not the same as corresponding retroflexes in other Australian languages. As this is the only study known to me that describes the realization of rhotically-released retroflex stops, the exact articulation and possible variation of this class cannot be further discussed here.

The third type of affricate is the laterally released stop. The inclusion of this type seems necessary since Ball & Rahilly (1999: 67f.) mention that laterally released retroflex stops [ʈɭ̊, ɖɭ] are possible to produce. Unfortunately, they do not provide example languages. Since the lateral is phonetically presumably more affricated than a lateral occurring in vowel context (due to the larger constriction in place of articulation), I claim that the laterally released stops described by Ball & Rahilly are actually lateral affricates such as the alveolar [tɬ] or [dɮ] found e.g. in the Na-Dené languages Navajo and Tlingit (Maddieson 1984). Evidence for the non-distinctiveness of laterally released stops and lateral affricates is taken from the fact that no phonetic description makes this distinction,[11] and furthermore no language seems to employ the two types distinctively. Masica (1991: 105) mentions that in the northwest West Pahari dialects Bhadrawahi and Bhalesi (Indo-Aryan languages) a ‘peculiar set of laterally-released apical stops’ exists, but transcribes these sounds as lateral fricatives, which is further evidence for the claim made here that there is no difference between laterally released stops and lateral affricates. The segments that occur in these dialects are [ʈɬ, ʈʰɬ, ɖɮ, ɖʰɮ].[12] According to O’Grady, Voeglin, & Voeglin (1966) the Pama-Nyungan language Adynyamathanha (also known as Wailpi), spoken in South Australia, also has lateral retroflex fricatives.

Lastly, the class of affricates sometimes includes stops with a nasal release (as in Kehrein’s 2002 classification). However, I could not find any language described as having a retroflex nasal affricate.

2.2.4.5 Laterals

As Ladefoged & Maddieson (1996: 183) point out, the place of articulation for laterals is usually the same as the place for the corresponding stop in the same

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[11] Even Ball & Rahilly (1999), who introduce the class of laterally released stops, do not explicitly distinguish it from lateral affricates and fail to point out the differences between them.

[12] I transcribed the segments with the corresponding IPA symbols according to Masica’s (1991) descriptions. Kehrein (2002: 6) employs the symbols [ʈˡ] and [ɖˡ] with a raising sign underneath the retroflex laterals for these speech sounds.

language, though the tongue shapes behind the constriction might differ. This suggests that retroflex laterals show the same articulatory characteristics and variation as the stops. Švarný & Zvelebil's (1955) x-ray study for Tamil and Telugu confirms this hypothesis, as it shows that both stop and lateral retroflex are subapical post-alveolar in these languages. Dixon (1980: 143) gives further evidence from Australian languages. According to him, the Australian retroflex lateral is a subapical post-alveolar just like the retroflex stop. Therefore, retroflex laterals are expected to show the same kind of variation as retroflex stops.

In Indo-Aryan languages we would expect to find an apical post-alveolar lateral. No articulatory study on Indo-Aryan laterals could be found to confirm this.

2.2.4.6 Rhotics

Post-alveolar rhotics articulated with a retroflex tongue shape are possible with three manners. These are the post-alveolar flap (in the IPA symbol chart described as a flap or tap), the post-alveolar central approximant, and the post-alveolar trill.

The retroflex flap [ɽ] could have been included in the class of stops, as it is often described as a flapped stop (e.g. by Laver 1994: 221) because the active articulator hits the passive one in passing. Phonologically, there is evidence for sharing a class with both stops and rhotics: Masica (1991: 97) describes that in many Indo-Aryan languages such as Panjabi, Hindi, and Sindhi the retroflex flap [ɽ] is in complementary distribution with the voiced retroflex stop [ɖ]. In Australian Warlpiri and Maung or African Gbaya and Shona, these segments pattern with rhotics. The retroflex flap is not articulated further back than alveolar. This is due to the tongue movement taking place during its articulation; the tongue tip is curled inwards and approaching the post-alveolar region but flaps out before the actual contact takes place. See figure 2.7 of two production stages of the flap based on Laver (1994: 223).

Figure 2.7 Two stages in the production of a retroflex flap: the retroflex onset (left), and the sliding from post-alveolar to alveolar during closure and release (right) both based on Laver (1994: 223).

Due to this large movement towards the alveolar ridge during the articulation, the flap [ɽ] is inherently less retroflex than e.g. a retroflex stop.

The retroflex trill is articulated with the tongue underside vibrating against the post-alveolar region. The IPA chart does not provide any symbol for this sound; Laver (1994: 220) represents it with an underlined apical trill [r̠], whereas traditional Dravidianists such as Emeneau (1984) use the symbol for an apical trill with a subscript dot [ṛ]. Spajić et al. (1996) explain that the first contact for a retroflex trill takes place further back than the subsequent contacts, i.e. there is a flapping out gesture observable during the articulation of the trill.

Some speakers of Malayalam have a retroflex trill (recall its dependence on the speech rate illustrated in 2.2.2). Ladefoged, Cochran & Disner (1977) describe this sound as ‘almost retroflex’, and one can conclude from this that the place of articulation for this segment is not as far back as for other retroflexes and that it is rather the tongue tip than the tongue underside that is involved in the articulation. The Toda retroflex trill investigated in Spajić et al. (1996), however, is a subapical post-alveolar. This indicates language-specific variation within the class of retroflex trills, comparable to the one observed for stops in 2.2.4.1.

The third type of retroflex rhotic is the approximant [ɻ]. This segment occurs e.g. in Australian languages where, according to Dixon (1980), it is articulated almost as far back as the retroflex stop. McDonough & Johnson (1997) demonstrate that the Tamil retroflex approximant shows a constriction at the hard palate. Contrary to the other two types of retroflex rhotics, the approximant does not show any evidence of a forward motion during the consonant closure.

Australian languages usually employ four coronal stops, nasals, and laterals, but only two rhotics which are both apical. Dixon (1980: 144) describes these rhotics as apical trill and subapical post-alveolar continuant. The latter can also be realized as a post-alveolar trill, typically at the end of a stressed syllable. The distinction between rhotics in Australian languages therefore seems to be not in the manner but in the place of articulation, namely apical alveolar versus retroflex. The same variation in manner but consistency in place can be observed in Hausa rhotics, which are apical trill versus retroflex flap or approximant (Newman 1980).

In sum, retroflex rhotics seem to be prone to a large degree of variation, not only in the place of articulation and active articulator, but also in the actual manner of articulation.

2.2.4.7 Retroflex vowels

Vowels can show some kind of secondary articulation as ‘apico-post-alveolarized, advanced velar approximants’ (Catford 1977: 150), a variant that is often referred to as ‘retroflex vowels’. Catford (1977: 192) points out that these vowels involve a raising and sometimes drawing backwards of the tongue tip, which results in apico-post-alveolarized or sublamino-prepalatalized articulations. American English is reported to have retroflexed vowels such as [ɔ^{ɻ}] in *board*. Further instances can be found in the Uto-Aztecan language Serrano and the Mesoamerican Tarascan (Bhat 1973: 38). Vowel retroflexion typically occurs pre-rhotically as e.g. in British and American English (Wakelin 1972), see section 4.4 below. These vowels are also called ‘r-coloured’ or ‘rhotacized’ (e.g. by Wells 1982: 139 and Laver 1994: 270). An illustration of such an articulation is given in figure 2.8.

The tongue configuration for a retroflex vowel is nearly identical to the first stage of the retroflex flap, see the left side of figure 2.7, which is also based on Laver.

Figure 2.8 Retroflex vowel, based on an x-ray tracing by Laver (1994: 271).

Catford (1988: 161f.) distinguishes between *retroflexed* and *rhotacized* vowels, the former affecting only open vowels, and the latter referring to the sound [ɚ] as in the American English word *bird*. Rhotacized vowels are, according to Catford, articulated with a redrawn tongue tip or with a bunched, retracted tongue body. The latter do not show any retroflex articulation and are therefore not topic of the present dissertation. Trask (1996: 310) unites both articulations, referring to both as retroflexed or 'r-coloured', and defines them as having the distinct acoustic quality of a lowered third formant.

The present dissertation is primarily concerned with retroflex consonants. Where retroflex vowels are discussed, they are assumed to be articulated as in figure 2.8.

2.2.5 Language family

The association of degree of how far the tongue tip is bent backwards with a specific language family has been made repeatedly in phonetic and phonological literature. Catford (1977: 153) e.g. distinguishes two types of tongue tip bending (retroflexion) and correlates them with the two language families found on the Indian subcontinent, namely Indo-Aryan and Dravidian. He states that the retroflex stops in Indo-Aryan languages are articulated with the underside of the tongue (subapical area) against the back of the alveolar ridge, an articulation he terms 'sublamino-post-alveolar'. Retroflex segments in Tamil and other Dravidian languages however are articulated with the underside against the prepalatal area, according to Catford, and termed by him 'sublamino-prepalatal'. He calls this type of gesture 'the most retroflex of retroflex articulation'. The distinction between moderately retroflexed segments in Indo-Aryan languages and extremely retroflexed segments in Dravidian language is supported by phonetic studies by e.g. Švarný & Zvelebil (1955), Balasubramanian (1972), and Ladefoged & Bhaskararao (1983). Švarný & Zvelebil compare X-rays of retroflex stops of Tamil, Telugu (both Dravidian) and Hindi (Indo-Aryan). They used one speaker of each language, and the results show that the Tamil speaker has the most retroflexed stop with an apical-prepalatal articulation. Ladefoged & Bhaskararao (1983) evaluate the articulation of retroflex stops of several Hindi and Telugu speakers via x-rays and found a systematic difference. The Telugu stops are all considerably retroflexed, with a subapical articulator and prepalatal place of articulation, whereas the Hindi stops are mostly apical and post-alveolar. Thus, the difference in the degree of tongue tip bending in languages spoken on the Indian subcontinent can be correlated with the distinction of the two language families.

Ladefoged (1964) examines sounds of the West-African language Ewe and the neighbouring Central Togo languages Logba, Siwu, and Gẽ palatographically. He notes that the retroflex voiced stops occurring in these languages are less retroflexed than those of many Indian languages such as Hindi. The exact articulatory description, however, shows that the retroflex in Ewe has "the tip of the tongue against the alveolar ridge (usually the posterior part)" (Ladefoged 1964: 20). Ladefoged's generalization seems to indicate that West-African languages show a common characteristic of apical post-alveolar articulation in the retroflex voiced stops.

The two North-Germanic languages Norwegian and Swedish that employ retroflexion both show apical articulation and a place of constriction that is rarely further back than the post-alveolar region (see Simonsen et al. 2000 on Norwegian, and Lindblad & Lundqvist 1994, 1997 on Swedish). This could be interpreted as a trait of North Germanic.[13]

Retroflex segments in Australian languages do not show one homogenous articulation. According to Butcher (1992: 14), some languages such as Western Arrernte (belonging to the Arandic branch of Pama-Nyungan), Yindjibarndi (south-western branch of the Pama-Nyungan subfamily) and Tiwi (Tiwian subfamily) have retroflex sounds that are articulated with the tongue tip just behind the alveolar ridge, whereas others such as Adynyamathanha (south-western branch of Pama-Nyungan) and Gupapuyngu (Yuulngu branch of Pama-Nyungan) have subapical retroflex segments. Hence, no common retroflex characteristic for all Australian languages can be stated. Further investigations into the numerous Australian sub-families might result in some traits that are shared within subfamilies.

In general, languages belonging to the same language family tend to employ a similar type of retroflex segment, though this does not seem to hold for all language families, as exemplified by the Australian languages.

2.2.6 Inventory size

The degree of articulatory variation is often influenced by the inventory size of the respective languages. Inventory size is partly interrelated with the factor language family described in 2.2.5, as related languages often show similar segment inventories.

Both English and French have only one anterior coronal for any manner (apart from the fricatives) and therefore allow a considerable amount of articulatory

[13] Optional retroflex articulation of rhotics is reported for various Germanic languages such as English (Ball & Rahily 2000), German (Wiese 2001) (for the area North-East of Dresden) or Dutch (Verstraeten & Van de Velde 2001) (as a variant in the North of the Netherlands). This variation is ignored here as it concerns only one manner class (which might affect other manners via spreading as is the case e.g. in some of the rhotic variants of English) and mostly only regional variants of these languages.

variation, see for instance Dart's (1991) study on alveolars in French and English. The situation is different for languages with large coronal inventories such as Australian languages, where the existence of other, articulatorily close classes prohibits large variation of e.g. the retroflex class. Butcher (1992) investigated several Australian languages and found that the only apical coronal in the Kalaw Kawaw Ya dialect of the Western Torres Strait language is often articulated as retroflex and displays far more variation than either one of the apical segments in Australian languages with a two-way apical contrast. To examine how far the inventory size can influence the degree of tongue tip bending, let us look closely at two different retroflex manners, namely stops and fricatives, and the correlation between their articulation and the size of the inventory.

Stops. To account for the articulatory difference between Hindi and Tamil retroflex stops exemplified in figure 2.4 above in terms of language system, there should be a difference in their coronal inventories. Since it shows less tongue tip bending in its stop, Hindi is expected to have a smaller coronal inventory than Tamil. And indeed, Hindi has two coronal plosive series,[14] a dental and a retroflex (Ohala 1994), see (1a), whereas Tamil has four: a dental, an alveolar, a retroflex, and a palato-alveolar (Christdas 1988), see (1b).

(1)	(a)	Hindi	[t̪, ʈ]	(or: [t̪, ṭ])
	(b)	Tamil	[t̪, t, ʈ , t̠]	
	(c)	Toda	[t̪, t, ʈ]	
	(d)	Kannada	[t̪, t, ʈ]	

Thus the pressure of many segments in the coronal region seems to cause a more retracted articulation of the retroflex plosive for Tamil. Toda supports this hypothesis. Like Tamil, it has a subapical post-alveolar retroflex stop (Shalev, Ladefoged & Bhaskararao 1993) and two additional coronal stops, a laminal dental and an apical alveolar, see (1c). The existence of one further apical element in a language, not necessarily a four-way coronal contrast, seems therefore to cause a subapical articulation of retroflex stops. Kannada (another Dravidian language) also has a subapical retroflex stop and the same three-way coronal distinction as Toda, see (1d), and hence supports this point.

As all the languages characterized by a subapical stop and a large inventory mentioned up to now are Dravidian, one could argue that these two characteristics are specific to this language family (see 2.2.5 above) or are areal features that spread together, but are not correlated. In order to refute this argument, languages from families other than Dravidian have to be found that behave similarly. Australian languages with a four-way coronal contrast of apical alveolar, laminal dental, retroflex, and laminal post-alveolar stops (but also nasals and laterals) seem to be ideal for this purpose. Eastern Arrernte (Butcher 1995) e.g. has such a four-way

[14] 'Series' is used to denote a voiced and/or voiceless segment in one place of articulation such as dental, alveolar etc. The segments [c, ɟ, ç, ʑ, ɲ] are assumed to be alveolo-palatal, not palatal (following e.g. Keating 1991, Hume 1992, Hall 1997a) and thus belong to the coronal sounds.

contrast and a retroflex that is apical palatal, see (2), thus providing evidence for the systemic pressure of a large inventory on subapical retroflex articulation.

(2) Eastern Arrernte [t̻, t, ʈ , t̠]

Other Australian languages, however, do not support this inventory theory. Butcher's (1992) palatographic studies of the retroflex stops in five of these languages with the same two-way apical contrast as Eastern Arrernte (Warlpiri, Kunwinjku, Murrinh-Patha, Nyangumarta and Western Desert) indicate that the retroflex stops vary from apical post-alveolar in Nyangumarta to subapical palatal in Murrinh-Patha, with the remaining three languages somewhere in-between. The apical alveolars, however, are articulated in exactly the same way in all five languages. Thus the larger inventory incurs a noticeable restriction on the variation allowed within the alveolar class, but not within the class of retroflexes.

One can conclude from this that a large coronal inventory does not necessarily impose a subapical post-alveolar articulation on the retroflex stop, though there is a general tendency towards more retracted retroflexes in larger inventories. Small inventories with a retroflex stop, on the other hand, seem to have retroflex segments articulated further front and with the tongue tip. Support for this comes from the West-African language Ewe, which has two coronal (voiced) stops, one laminal denti-alveolar and an apical post-alveolar retroflex, see (3).

(3) Ewe [d̻, ɖ] (or: [d̻, ḍ])

Here the relatively small coronal inventory allows a segment that shows almost no bending backwards of the tongue tip. Similar observations can be made for Norwegian, which has a laminal dental and an apical (post)alveolar retroflex as the only coronals (Simonsen et al. 2000), see (4).

(4) Norwegian [t̻, ʈ] (or: [t̻, ṭ])

Fricatives. The correlation of inventory size with degree of tongue tip bending seems also to work for fricative inventories. The difference in retroflex fricative between the Tamil laminal post-alveolar and the apical post-alveolar in Toda as illustrated above in figure 2.5 can be explained by differences in the inventory. Though both languages are Dravidian, Tamil has three coronal fricatives, see (5a), whereas Toda is the only language of this family with four coronal fricatives, namely a laminal alveolar, an apical post-alveolar, a laminal post-alveolar, and a subapical palatal, see (5b). Hence the subapical palatal in Toda might be due to the large fricative inventory.

(5) (a) Tamil [ð, s, s̢] (or [ð, s, ṣ])
(b) Toda [s̻, s̠, ʃ, s̢] (or [s̻, ṣ, ʃ, s̢])

The coronal fricative system of Toda is of further interest for the present study, as its apical post-alveolar is very similar in place of articulation and active articulator to the retroflex fricative in Tamil (depicted in figure 2.5 on the left). Based on this similarity, one could postulate that Toda has two types of retroflex fricatives, a subapical palatal (like the retroflex stop in Dravidian languages) and an apical post-alveolar (like the Tamil fricative), as Ladefoged & Maddieson (1986) did. In later work, Ladefoged (1994), Ladefoged & Maddieson (1996), and Shalev et al. (1993) disprove this claim, arguing that there are "no two degrees of retroflexion" in Toda (Ladefoged 1994: 20). As elaborated in the present chapter, degree of tongue tip bending is variable, and some retroflex sounds do not even show a bending of the tongue tip at all, recall the Ewe stop. Especially fricatives typically have a lesser degree of tongue tip bending than plosives or nasals, recall 2.2.4.3. Thus, Ladefoged et al.'s argumentation that Toda does not have two retroflexes because there are no two 'degrees of retroflexion' is not convincing as no definition of retroflexion is given by them. According to the phonetic descriptions of retroflex segments made above, the articulation of retroflexes can range from apical to subapical and from alveolar to palatal place of articulation. Both the Toda apical post-alveolar [s̠] and the subapical palatal [ʂ] fall into this range and thus can be classified articulatorily as retroflex. Chapter three will show that both Toda fricatives also comply with the acoustic criteria for retroflex. It remains to be discussed whether it is phonologically necessary or useful to distinguish two retroflex categories, and how they could be represented. This question will be dealt with in chapters 4 and 5.

As in the retroflex stop systems, the existence of four coronal fricatives in a language is not the decisive factor for the degree of tongue tip bending. The Bzyb dialect of Abkhaz, a Northwest Caucasian language, has according to Ladefoged & Maddieson (1996: 161f.) four coronals, three of them laminal (an alveolar, a post-alveolar, and an alveolo-palatal) and one apical, see (6).[15]

(6) Abkhaz [s̪, ʃ, ʂ, ɕ] (or: [s̪, ʃ, ṣ, ɕ])

The apical [ʂ] is a post-alveolar with slight tongue tip bending only. This might be due to the fact that there is no second apical and therefore no need for maximizing an articulatory difference between apical alveolar and subapical post-alveolar.

To complete this section on retroflex fricatives and their correlation with inventory size, a discussion of the post-alveolar fricatives in the Slavic languages Polish and Russian has to be included. As indicated already in 2.2.4.3, the Polish and Russian sounds are articulated with a flat, non-domed tongue middle and with a raised tongue tip (see also section 2.4 about the extent to which Polish fricatives conform to retroflex characteristics). With such a variant of retroflex, we would expect the coronal fricative inventory to be small.

(7) (a) Russian [s̪, ʂ, ʃː]
(b) Polish [s̪, ʂ, ɕ]

Both Russian and Polish, however, have a fricative inventory with three segments, a dental [s̪], a retroflex [ʂ], and a further post-alveolar fricative. In Russian, the additional fricative is a laminal post-alveolar, see (7a). This segment is usually

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15 Ladefoged & Maddieson use a different symbol for the laminal post-alveolar in Abkhaz because this sound differs from e.g. English [ʃ] in that it is articulated with the tongue tip behind the lower teeth, and does not have a sublingual cavity.

transcribed as [ʃʲː] but referred to as [ʃː] in this study, because it does not consist of a post-alveolar plus an additional short glide, i.e., it is not a real secondarily palatalized post-alveolar.[16] Polish has the additional alveolo-palatal [ɕ], see (7b). Russian and Polish thus have two laminal coronal fricatives besides the apical retroflex. The absence of a second apical coronal can explain why these two languages employ a retroflex that shows no backwards bending of the tongue tip, because there is no need for a maximal distinction between two apicals.

In sum, it has been shown that the articulatory variation of retroflex stops, fricatives, and also of other manners, if the findings can be transferred to them, can be partly accounted for by referring to the inventory system in which the retroflex segment occurs. Whereas small inventories with only one apical, namely the retroflex, allow considerable variation of the retroflex and also a place of constriction further front than the post-alveolar region, large inventories (i.e., those with two apicals and one or more laminals) generally show less variation and an articulation with a bent backwards tongue tip. It has to be pointed out that this is only a tendency and no universal regularity, as illustrated by the counterexamples above.

2.3 Common articulatory properties of retroflexion

As was shown in the previous section, the exact place of contact and the exact articulator of retroflex segments are subject to a large amount of variation, depending on several parameters. Furthermore, it was shown that the traditional property of retroflexes as a bending backwards of the tongue tip is not universally valid. Variation in the class of retroflexes seems to be larger than in any other articulatory class, which makes it difficult to find common properties that hold for all retroflexes.

The present section is concerned with defining more or less invariant characteristics that can be used as articulatory defining criteria for a retroflex articulation. Four such properties are proposed here, namely apicality, sublingual cavity, posteriority, and retraction. Not all of them occur in the same degree in all instances of retroflex segments, but they can be viewed as defining characteristics of a prototype retroflex; the more of these properties a segment has, the more retroflex it is.[17] Interrelations between these properties proposed here are developed in the following sections and summarized in 2.3.5. Seeming counterexamples of languages such as Polish, Russian, and Mandarin, which have retroflexes that do not have all four properties, are discussed in 2.4.

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16 The Russian laminal post-alveolar is not an alveolo-palatal [ɕ], either, see figure 2.13 below.

17 Shalev et al. (1993: 106) point out that retroflex stops have a lower jaw position than the other coronals. This property is not further developed here.

2.3.1 Apicality

As could be seen in the phonetic descriptions above, retroflexes mainly involve the tongue tip in their articulation, either its upper side (apical articulation) or its lower side (subapical articulation). Even in cases where no judgement on the involvement of the tongue tip can be made from the articulatory data, as is the case for some fricatives (e.g. the Tamil fricative in figure 2.5 left or the Mandarin fricative in figure 2.6), the tongue tip is not in resting position, i.e. behind the lower teeth, but raised. Usually, however, the tip of the tongue forms the actual constriction for retroflexes.

In the present study, the term ‘apicality’ is defined to refer to this involvement of the tongue tip. Apicality is meant here in a strict phonetic descriptive way. It is not used as a phonological feature such as e.g. ‘apicality’ in Williamson’s (1977) feature system or [–distributed] in traditional featural theories (e.g. Chomsky & Halle 1968 and Sagey 1986), since these feature values do not allow the inclusion of cases as the Tamil retroflex which does not show an active articulation with the tongue tip.

Retroflex segments share the characteristic of apicality with front apicals in the dental/alveolar region. All apical segments have in common that they consist of an extremely rapid gesture, as the tongue tip is the most flexible and quickest active articulator. In fast speech, this quick gesture is often reduced or lost, which explains the decrease of tongue tip bending with increased speed of speech described in 2.2.2. Retroflexes differ from front apicals in the place of constriction, which is defined as the second characteristic criterion, ‘posteriority’.

2.3.2 Posteriority

Retroflexion in the traditional sense refers to an articulation behind the alveolar region, usually described as ‘post-alveolar’ or sometimes ‘palatal’ (e.g. Catford 1977). This is termed ‘posteriority’ below, and is employed as one of the articulatory characteristics of retroflexion. Besides retroflexes, the segmental classes of palato-alveolars and alveolo-palatals are also posterior. Posteriority thus corresponds to [CORONAL, –anterior] in Feature Geometric notation (Sagey 1986), i.e., only segments articulated with the tongue tip or blade can be posterior. In order to distinguish the three posterior classes retroflex, palato-alveolar, and alveolo-palatal, further characteristics have to be used.

The two non-retroflex posterior segment classes, palato-alveolars and alveolo-palatals, are both laminal, thus differ from retroflexes in the characteristic apicality. Furthermore, they occur only with a fricative manner, whereas retroflexes can occur with all possible manners of articulation (see description in 2.2.4). A third point distinguishing these two classes from retroflexes is the shape of the tongue middle during their articulation: palato-alveolars and alveolo-palatals have a domed, i.e. raised, tongue middle; retroflexes a flat one (which is defined as belonging to the fourth property, ‘retraction’, see section 2.3.4).

Section 2.4 will discuss some retroflex sounds that lack the characteristic of posteriority, e.g. the Polish fricative. These exceptions only involve fricative manners of articulation.

Retroflexes typically involve a movement of the tongue tip from a posterior to a more anterior position during their articulation, a feature referred to above as “flapping out”. This flapping out could be treated as another, separate property of retroflexion. The present study does not adopt this view because flapping out, in contrast to the other characteristics introduced here, does not occur in the same way for all manners of retroflex articulation. Fricatives, for example, allow flapping out only at the onset of a following segment but not during the fricative constriction. Introducing this gesture as a separate property would thus imply that specific manners like fricatives are inherently less retroflex than e.g. stops or flaps, an implication avoided here. The flapping out gesture occurs almost exclusively with an apical articulation on a posterior place, and hence is assumed a possible concomitant of the properties ‘posteriority’ and ‘apicality’.

2.3.3 Sublingual cavity

A unifying criterion for retroflex segments seems to be their sublingual cavity, visible in all the x-ray tracings of the retroflexes given above. All sounds articulated with the tongue tip or blade on or behind the alveolar ridge evince a cavity beneath the tongue, due to the backwards displacement of the tongue front (Sundberg & Lindblom 1990: 1316). Keating (1991: 43) points out that this cavity increases in volume from palatal, alveolo-palatal (“hissing-hushing” in her terms), palato-alveolar, apical retroflex, to the sublaminal retroflex. The property of sublingual cavity is thus not unique to retroflex segments, but judging from Keating’s description it is largest for any kind of retroflex articulation. All segment classes with a sublingual cavity share also the property of ‘posteriority’, according to Keating’s definition above. They differ, however, in the criterion apicality, which is unique to retroflexes.

‘Sublingual cavity’ differs from traditionally employed articulatory descriptions of segment classes, which are usually restricted to the place of articulation and the active articulator.

Vowel context seems to affect the size of the front cavity systematically. As Sundberg & Lindblom (1990: 1315) point out, “everything else being equal, that cavity tends to be larger for [retroflex] tokens surrounded by /u/, intermediate for /a/, and smallest for samples with /i/.” The dependence of the sublingual cavity on context proves the aforementioned impossibility to find a property that is invariant for all retroflexes in all contexts.

2.3.4 Retraction

The property ‘retraction’ to be discussed in this section is not as obvious a characteristic of retroflexion as those proposed up to now and is the most controversial of all. Bhat (1974a) writes that retroflexion cannot be equated with retraction (defined by him as backing of the tongue body), because retraction does not occur exclusively with retroflexion. Furthermore, some retroflexes are said to occur without retraction, namely Lardil retroflex consonants and Badaga retroflex vowels.[18] It is argued here that all retroflexes - but also other sounds - show retraction.

In the phonetic literature, retraction is usually defined by the place in the vocal tract where the tongue retracts to, and distinguished into pharyngealization or velarization. The term pharyngealization is mostly used for a secondary vowel articulation (e.g. by Ladefoged & Maddieson 1996: 365) where the root of the tongue is drawn back towards the back wall of the pharynx. Velarization is understood as a secondary articulation where the tongue dorsum is raised towards the velum (e.g. definition by Trask 1996: 374). Brosnahan & Malmberg (1970: 67) define velarization as ‘the elevation of the back of the tongue toward the soft palate or rear wall of the pharynx’, which actually covers both velarization and pharyngealization as defined previously. Ladefoged (1971) points out that there is little difference between velarized and pharyngealized sounds[19] and says that no language distinguishes between these two. He goes on to say that

> [I]t is interesting to note that there is some similarity in quality between retroflex stops and velarized or pharyngealized stops. This is due to the fact that in all these sounds the front of the tongue is somewhat hollowed (Ladefoged 1971: 208)

The property ‘retraction’ introduced here is thus defined as a displacement of the tongue back towards the pharynx or velum. A schema of these possible displacements is given in figure 2.9, based on x-ray tracings of velarized and pharyngealized segments in Laver (1994: 326ff.) and Ladefoged & Maddieson (1996: 365).

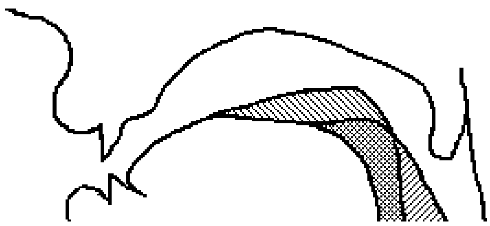

Figure 2.9 Retraction, i. e. velarization (upper movement) and pharyngealization (lower movement) in comparison to neutral tongue position

These displacements of the tongue towards the velum or the pharynx are sometimes referred to as ‘tongue backing’, as by Bhat (1974a) and Stevens (1998).

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18 For a detailed discussion of Bhat’s claims the reader is referred to Hamann (2002a).

19 An interesting language-specific case of the similarity between pharyngealization and velarization is Russian. Whereas Russian consonants are traditionally described in terms of the opposition palatalized vs. velarized, Bolla (1981: 70) describes the latter as ‘pharyngealized’ because he ‘found the movement of the root of the tongue and the postdorsum towards the pharyngeal wall to be more important than that towards the soft palate’.

It is difficult to see retraction in x-ray tracings of retroflex segments clearly, as most of these pictures do not even show the pharyngeal area and the tongue position therein. Furthermore, often no comparison to the normal, non-retracted tongue position can be made, as x-ray studies usually do not include a figure of the articulators at rest.

The legitimacy of combining the distinct secondary articulations of pharyngealization and velarization as a single property is further confirmed by the fact that they are described as resulting in the same acoustic effects, see section 3.2.4.

The property 'retraction' is not identical to the feature 'retracted tongue root', henceforth RTR (opposed to 'advanced tongue root', see Halle & Stevens 1969), because this articulatory setting involves a pharyngeal constriction at a lower level than for pharyngealization, according to Laver (1994: 411). Furthermore, RTR is usually only used for vowel articulations (see Ladefoged's 1964 description of Igbo vowels). Retraction as defined here is also different from McCawley's (1966) feature 'retracted articulation' by which he distinguishes dentals from alveolars and retroflexes from palatals (amongst others), the second item in each pair being [+retracted] (and thus ascribing retroflex a non-retracted status). The property 'retraction' is best captured by the traditional phonological feature [+back] (e.g. Clements 1991, Hall 1997a, Lin 1989, Rubach 1984).

Cooccurrence of retroflexion with retraction can be articulatorily explained. The tongue, in order to be able to move its tip upwards and into a displaced position in the post-alveolar region, stretches and pulls backwards (Spencer 1984: 30), which results in a lowered tongue middle and retracted tongue back. Tongue lowering is thus a concomitant of the property 'retraction', or the reverse.

'Lowering' describes the flat tongue middle that is found with retroflex articulation. In many phonetic descriptions the lowering of the tongue middle in retroflexes is described as a concaving of the dorsum (Brosnahan & Malmberg 1970: 46) or a less convex shape of the tongue than in lamino-post-alveolar articulations (Catford 1977: 157). The shape of the tongue middle is actually one of the main differences between retroflexes and palato-alveolars or alveolo-palatals: the latter two have a raised tongue middle, sometimes called "domed" (e.g. Ladefoged & Maddieson 1996: 148), in contrast to the lowered one of retroflex segments.

The retraction of the tongue back and the lowering of the tongue middle that occurs with retroflex articulation is given schematically in figure 2.10, where the grey underlying figure indicates the tongue position at rest.

Bhat (1974a) argues that retraction is not restricted to retroflexes but mostly occurs with apicals in general. Stevens, Keyser & Kawasaki (1986: 436), however, claim that a fronted tongue body provides a more favourable posture for an apico-alveolar articulation, i.e. that a non-retroflex apical usually occurs with fronted tongue body.

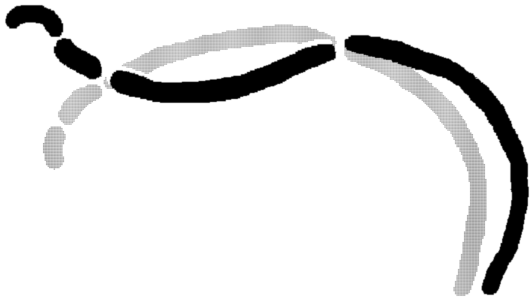

Figure 2.10 A schematic illustration of tongue gestures co-occurring with tongue tip retraction. Underlyingly grey are the tongue parts at rest, from left to right: tip, blade, middle (or pre-dorsum), and back (or post-dorsum) as defined in section 2.1.

From comparing the realization of apico-alveolars in different languages we know that this class can be non-retracted. For example, British English, Dutch, and Catalan have a non-velarized lateral in the onset and a velarized lateral in coda position.[20] Thus retraction cannot be assumed to occur exclusively with retroflexes. Nevertheless, as retraction is not used as the single defining criterion for retroflexion but along with the other three properties developed above this does not cause any definition problems.

Further evidence in the phonetic literature for the correlation of retroflexion and retraction besides Bhat (1974a) is Catford (1977: 157) who writes that the tongue body for retroflex segments shows some velarization. Language-specific descriptions of a correlation between retroflexion and retraction are, for example, Hamilton (1980: 21), who uses the terms velarization and retroflexion interchangeably for the post-alveolar fricative in Polish, and Wood (1996), who writes that the Bulgarian retroflexed /r/ involves a pharyngeal tongue body gesture. In Ponapean, a Micronesian language spoken on the Pohnpei Island, the velarized counterpart of the dental t is a retroflex affricate (Rehg 1973), giving further evidence for the inherent retraction of retroflexes (see section 4.4.1 below).

Using 'retraction' as a defining characteristic of retroflexion poses problems with languages that are said to have a distinctively non-retracted (i.e. non-velarized or non-pharyngealized) retroflex segment. The Australian language Lardil is the only language known to me which is supposed to have a phonetically and phonologically non-velarized retroflex fricative (Hall 1997a, 2000a, and Wilkinson 1988, both based on Stevens et al. 1986). The phonetic evidence for this claim comes from Hall (1997a: 49) who gives midsagittal tongue tracings of non-velarized and velarized retroflexes from the languages Lardil and Polish, respectively, to

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20 Retraction of the tongue body (towards the velum) also seems to occur distinctively in the articulation of velar consonants, though for velars this is the primary constriction in the vocal tract, not an additional secondary one.

illustrate the difference. The source for the figure of the non-velarized retroflexes in Lardil is given as Stevens et al. (1986). Stevens et al., however, do not provide any graphic illustrations of the Lardil coronal. The only figure that might have served as the basis of Hall's figure is a schematized retroflex stop in figure 20.4 on page 433, based on Ladefoged & Bhaskararao (1983) and Wierzchowska (1965). These sources, though, investigated retroflexes in Hindi, Tamil, and Polish. The schematic retroflex sound in Stevens et al. shows a distinct backing of the tongue body and is explicitly described as 'more backed' than an apical dental or a laminal post-alveolar in the text. In their phonetic description of Lardil sounds at a later point, Stevens et al. (p. 444f.) observe that [+distributed, −anterior] segments, i.e. laminal post-alveolars, are [−back] in this language. Hall (1997a) presumably misapplied this correlation to [−distributed, −anterior], i.e. retroflex, segments and concluded that Lardil is a language with [−back], i.e. non-velarized, retroflexes. A discussion of the phonological inadequacy of the distinction between velarized and non-velarized retroflexes in Lardil can be found in Hamann (2002a: 17ff.).

Though the primary concern of the present study is retroflex consonants, let us shortly look at the vowel system of the Dravidian language Badaga (spoken in the Indian state of Tamil Nadu), which is another apparent counterexample to the claim that velarization always co-occurs with retraction. According to Bhat (1974a: 234), Badaga contrasts plain, retroflex, and retracted vowels. Using retraction and retroflexion contrastively implies that they do not co-occur together in this language. Bhat bases his description of Badaga vowels on Emeneau (1939), who, however, describes the three-way contrast as one of 'non-retroflexed, half-retroflexed, and fully-retroflexed vowels'. Bhat does not motivate his reanalysis of these vowels, so we follow Emeneau's description, which poses no counterevidence for the assumption that the characteristic 'retraction' holds for retroflex vowels, too. Summing up, no language seems to exist with a non-retracted retroflex.

Besides the claim that non-velarized or non-pharyngealized retroflexes do not occur, the retroflex property 'retraction' introduced here has a further implication. If retroflex segments are inherently retracted, they should not be compatible with secondary palatalization, because a simultaneous articulation of palatalization and velarization or pharyngealization is articulatory impossible. The palatalization of segments involves a raising of the middle of the dorsum and a lowering of the tongue back, whereas retraction has the opposite articulatory consequences of flattening the middle of the dorsum and raising the back. Both gestures cannot co-occur, as the non-existence of a segment with secondary palatalization and velarization or pharyngealization in the languages of the world attests. Nevertheless, one finds references in the literature to palatalized retroflexes in languages such as Toda (Shalev et al. 1993; Spajić, Ladefoged & Bhaskararao 1996) and Kashmiri (Bhat 1987). I will argue that these segments are not retroflex (namely that palatalization of retroflexes triggers a change from a retroflex to a palato-alveolar articulation). This point will be developed in detail in section 2.5 below.

2.3.5 Summary of characteristic properties

In sections 2.3.1 to 2.3.4 above, four articulatory characteristics for retroflex segments were described, namely apicality, posteriority, sublingual cavity, and retraction. Looking at them separately, none of them is totally new for defining retroflexion, as they have been mentioned in connection with retroflexion in the phonetic and phonological literature before, though not necessarily with these terms and with a narrower definition in the case of retraction and apicality. Using the four of them together as defining criteria for retroflexion, however, is a novel approach.

The bending backwards of the tongue tip and the flapping out of the retroflex articulation have not been introduced as separate properties for the following reasons. As has been shown in 2.2, the tongue tip often fails to bend backwards in a retroflex, and hence this property would be violated by a large number of segments traditionally considered retroflex. Furthermore, if the two properties apicality and posteriority are met, this includes a possible bending backwards of the tongue tip, as the property apicality includes subapical, but it does not necessarily require it. Thus, the bending backwards of the tongue tip does not have to be stated as a separate property. Concerning the flapping out, it has been shown in 2.2 that not all retroflex manners include this gesture.

As has been indicated in their definitions, the proposed four properties are interrelated, i.e. some of them imply the presence of others. Posteriority implies the presence of a sublingual cavity, which means that a posterior articulation always co-occurs with a sublingual cavity. This entailment is given in (8a). Furthermore, the combination of some pairs of properties automatically entails the presence of the remaining two: apicality and posteriority imply a retracted articulation with sublingual cavity, see (8b), and posteriority and retraction imply apicality and a sublingual cavity, see (8c). Finally, two properties imply the presence of a third, thus a sublingual cavity plus retraction implies an apical articulation, see (8d), and apicality plus sublingual cavity implies retraction, see (8e).

(8)	(a)	posteriority	→	sublingual cavity
	(b)	apicality & posteriority	→	retraction, sublingual cavity
	(c)	posteriority & retraction	→	apicality, sublingual cavity
	(d)	subling. cavity & retraction	→	apicality
	(e)	apicality & sublingual cavity	→	retraction

The criterion ‘retraction’ makes some implications on the articulatory restrictions for retroflex segments that have not been proposed before. It predicts the absence of non-retracted (i.e., non-velarized or non-pharyngealized) retroflexes in languages of the world, which could be attested by showing that Lardil, the only known counterexample, does not have such a segment, either. A second implication is that secondary palatalization of retroflexion is impossible, because the result would have to be apical and laminal at the same time. This point will be further developed in 2.5 below.

2.4 Retroflex fricatives in Slavic languages

Having established four properties for retroflexion, this section applies these properties to two languages of a single family, namely Slavic, as a contribution to the analysis of retroflex consonants in this group. The post-alveolar fricatives[21] in the two Slavic languages Polish and Russian will be shown to be retroflex. Though traditionally described as palato-alveolar [ʃ], it has been argued by e.g. Keating (1991) and Hall (1997a) that the Polish fricative should be considered phonetically and phonologically to be retroflex. Keating (1991) argues similarly in favour of the retroflex quality of the Russian segment, though only on acoustic grounds, without giving a proper definition of retroflex. Whether these fricatives in Polish and Russian behave as retroflex phonologically as well, will be dealt with in chapter 4. The difference between retroflex and non-retroflex post-alveolar fricatives in Slavic languages was discussed in Hamann (2002b), where I show that Bulgarian, in contrast to Polish and Russian, has a non-retroflex laminal post-alveolar fricative. Hamann (2002b) also deals with Czech, but found no coherent phonetic results. Furthermore, there was no phonological evidence but also no counterevidence for concluding that the Czech post-alveolar is retroflex.

2.4.1 Polish

Polish has a fricative articulated in the post-alveolar region, as exemplified by the data in (9).[22]

(9)	*Word-initial*	*word-medial*	*word-final*
	szal [ʃal] ‘scarf’	kasza [ˈkaʃa] ‘groats’	lekarz [lɛkaʃ] ‘physician’

Traditionally, this sound is described as apical palato-alveolar, e.g. by Rubach (1984) and Wierzchowska (1980), and referred to with the IPA symbol [ʃ], e.g. by Dogil (1990). Ladefoged & Maddieson (1996: 155) compare this segment to the post-alveolar fricative in Mandarin, see figure 2.6, but argue that both sounds do not belong to the class of retroflexes, as they are laminal flat post-alveolars. At a later point (p. 154) Ladefoged & Maddieson refer to these sounds as ‘flat post-alveolar (retroflex)’ and use the alveolar symbol with a subscript dot for them, which is a traditional way of transcribing retroflex sounds used in studies of the languages of the Indian subcontinent. Thus Ladefoged & Maddieson’s classification of the Polish (and Mandarin) sound with respect to retroflexion is unclear, and even less so are the criteria for their classification. Keating (1991) argues that the Polish sound gives an acoustic impression similar to that of other retroflexes, hence can be included into the class of retroflex sounds. But she does not give any articulatory criterion either.

[21] The discussion in this section is restricted primarily to the voiceless post-alveolar fricative in the respective languages, but the argumentation can be extended to the voiced counterpart and to the affricate series as well (recall section 2.2.4.4 on the articulatory similarity of retroflex fricatives and affricates).

[22] The IPA symbol [ʃ] is used for the Polish and Russian examples in order to avoid any implications on their status before looking at their exact articulation.

Let us apply the four properties of retroflexion discussed in 2.3 to the Polish sounds, starting with apicality. The literature differs on the description of the active articulator of the Polish fricative. Biedrzycki (1974: 20ff.), Catford (1988: 90f), Dogil (1990), and Spencer (1986) all describe it as apical, Ladefoged & Maddieson (1996: 154) call it laminal. Ladefoged (2001: 151) describes it as a sound produced with a raised tongue tip, and Keating (1991) says it is variable. An x-ray tracing of the Polish post-alveolar voiceless fricative, given in figure 2.11 (based on Wierzchowska 1980: 64), shows that the tongue tip is not in resting position for this sound, thus 'apicality' (as defined in 2.3.1) is satisfied. Tracings from other sources (e.g. Ladefoged & Maddieson 1996: 154) show a similar articulation.

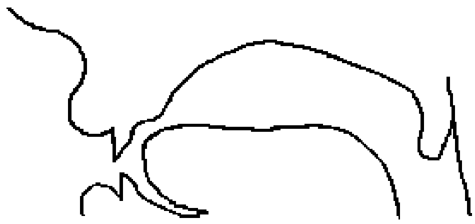

Figure 2.11 Polish post-alveolar with apical alveolar articulation (based on Wierzchowska 1980: 64)

Concerning 'posteriority', the Polish sound is generally described as post-alveolar. The x-ray tracing in figure 2.11, however, indicates a place of articulation that is at the alveolar ridge, and thus further front than defined for 'posteriority'. The property of posteriority thus seems not to be fully fulfilled by the Polish sound.

The sublingual cavity of the Polish segment is clearly discernible from figure 2.11, and the literature (such as Keating 1991) agrees on its existence, thus the criterion of 'sublingual cavity' is fulfilled. In cases where the shape of the tongue is described (e.g. in Keating 1991 and Ladefoged & Maddieson 1996), there is agreement on its lowered, backed nature, which fulfils the definition of 'retraction'.

Though not fulfilling all four parameters of retroflexion, the Polish sound can be classified as retroflex on the grounds of its apicality, its retraction, and the existence of a sublingual cavity in its articulation.

2.4.2 Russian

The Russian post-alveolar fricative, exemplified by the data in (10), is also traditionally described simply as a post-alveolar fricative.

(10)	*Word-initial*	*word-medial*	*word-final*
	šag [ʃak] 'step'	pošel [pʌˈʃol] 'went'	naš [naʃ] 'our'

The notion of retroflexion is never mentioned in the literature, with the only exception of Keating (1991). The sound in question is illustrated in figure 2.12 (based on Bolla 1981: plate 60).

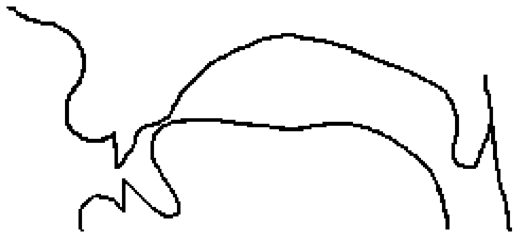

Figure 2.12 Russian post-alveolar fricative, based on an x-ray tracing by Bolla (1981: plate 60).

Bolla (1981: 71) describes this sound as a mediodorsal alveolo-palatal,[23] but the x-ray tracings from the same source show that this sound-class is articulated with a raised tongue tip. Keating (1991: 35) even states that some x-ray tracings of the post-alveolar fricatives in Russian made by Oliverius (1974) show a bending backwards of the tongue tip. Hence the criterion of apicality is fulfilled.

Though described as post-alveolar, the place of articulation in figure 2.12 seems to be the alveolar region (according to the definition and illustration given in 2.1), so the Russian fricative is not for certain posterior. Its sublingual cavity is visible in the x-ray tracing of figure 2.12.

Regarding retraction, phonetic descriptions on the Russian sounds explicitly mention a velarized and flat tongue shape, e.g. Bolla (1981: 90), and Jones & Ward (1969: 134). Maddieson (1984: 226) even uses special diacritics to indicate velarization for these sounds: [ʃ̴] and [$ʒ^{ɣ}$]. Catford (1977: 192) says that the Russian apico-post-alveolars have "the part of the tongue immediately behind the apex and the blade slightly hollowed, and the back slightly raised, giving a somewhat velarized effect." In addition, the x-ray tracing in figure 2.12 shows a flat tongue shape and a distinct retraction of the tongue body, so there is no doubt about the retraction of this sound.

Like the Polish post-alveolar, the Russian fricative definitely fulfils three properties of retroflexion, although the property of posteriority could not be clearly determined.

2.4.3 Slavic post-alveolar fricatives as non-prototypical retroflexes

Summing up the results of the comparison in this section, all three Slavic fricatives fulfil the criteria of apicality, sublingual cavity, and retraction. Posteriority, however, is a property that is not consistently present in the Slavic sounds. Whether the post-alveolars segments in Polish and Russian behave phonologically like post-alveolars, i.e. [-anterior], is a point that will be discussed in chapter 4. The present discussion looks at the phonetic criteria only. Since three criteria are fulfilled, the Slavic post-alveolar fricatives can be classified as retroflex, though they do not

[23] This description by Bolla refers to both [ʃ] and [ʃ:], which differ strongly in their articulation, cf. section 2.5 below, where I argue that the first one is retroflex and the second one laminal post-alveolar.

conform to the most prototypical retroflex fricative such as the fricative in e.g. Toda, which satisfies all four criteria but which is crosslinguistically extremely rare.

Altogether, a segment is still retroflex if it has all criteria except posteriority satisfied. The question has to be posed here whether any three criteria are sufficient, or whether it is only posteriority that can be lacking for a retroflex class. To answer this question, all other combinations of three of the four properties have to be examined. These possibilities are given in (11).

(11)	(a)	posteriority & subl. cavity & retraction	violates (8c), (8d)
	(b)	apicality & posteriority & retraction	violates (8a), (8b), (8c)
	(c)	apicality & posteriority & subl. cavity	violates (8b), (8e)

A sound with all retroflex properties present except for apicality, see (11a), would be a laminal post-alveolar with a sublingual cavity and retraction. Posteriority with a sublingual cavity is possible in a laminal post-alveolar, but this cannot be combined with retraction, since a laminal articulation always involves a raised tongue middle, i.e. a bunched tongue (see e.g. x-ray tracings of laminal consonants in general in Laver 1994, or language-specific for Toda in Shalev et al. 1993), which cannot be combined with a flat tongue middle and a retracted tongue back. This means that a segment with the criteria posteriority, sublingual cavity, and retraction but without apicality is articulatorily impossible. See also the implications (8c) and (8d) which require the presence of the property apicality in this combination.

The second property that could be missing is the sublingual cavity, see (11b). As a posterior articulation always entails a sublingual cavity (recall the entailment in (8a)), such a segment is articulatorily impossible. Finally, retraction of the tongue body could be missing, see (11c), but apicality and posteriority is only possible with a retracted tongue back, see (8b), hence also the third possibility of one missing property cannot be articulatorily realized. Thus, only ‘posteriority’ can be lacking from a retroflex, as all other combinations of one missing criterion are articulatorily impossible.

What happens now if two characteristic properties are not present in a segment; can this still be a retroflex? Combining two properties of the set of four gives us six possibilities, all listed in (12).

(12)	(a)	apicality	&	posteriority	violates (8a) and (8b)
	(b)	apicality	&	subl. cavity	violates (8e)
	(c)	apicality	&	retraction	realized as velarized alveolar apical
	(d)	posteriority	&	subl. cavity	realized as laminal post-alveolar
	(e)	posteriority	&	retraction	violates (8a) and (8c)
	(f)	subl. cavity	&	retraction	violates (8d)

Four of them, (12a), (12b), (12e), and (12f), are articulatorily impossible because of the entailments stated in (8), e.g. the combination of posteriority and retraction in (12e) to the exclusion of apicality and sublingual cavity is impossible, as apicality is entailed by the implication (8c) and sublingual cavity by (8a) and (8c).

The remaining two possibilities (12c) and (12d) are non-retroflex. Apicality and retraction alone (12c) yield a dental or alveolar apical with secondary velarization or pharyngealization. And a segment that fulfils the properties of posteriority and sublingual cavity exclusively, see (12d), is a laminal post-alveolar with a non-retracted tongue back. Toda contrasts such a fricative with a retroflex fricative that meets the requirements of all properties, and hence these two criteria are also not sufficient for defining retroflexion. The overall conclusion is that a segment satisfying two properties only of the four defined here for retroflexion either is unpronouncable or does not fall into the category retroflex.

2.5 Secondary palatalization of retroflexes

In this section it is argued that palatalized retroflex segments do not exist *phonetically*, as the two articulatory gestures of palatalization and retraction cannot be produced at the same time. It is shown that instead, the process of palatalization triggers a change in the retroflex segment from apical to laminal (as proposed already in Hall 2000), from flat, low tongue middle to bunched, raised tongue middle, and from retracted tongue back to fronted tongue back; i.e. from a retroflex which satisfies all four properties of retroflexion defined in 2.3 to a segment which satisfies only two of them (namely posteriority and sublingual cavity) and thus is non-retroflex. The analysis of secondary palatalization in section 6.3.3 will show that in some cases secondary palatalization of retroflexes is phonologically possible, though it still remains phonetically impossible.

Evidence for the claim that palatalized retroflexes are non-existent is found in Maddieson’s (1984) typological study, which lists no language with a phonemic palatalized retroflex segment. Only two counterexamples could be found in the phonetic and phonological literature, namely Toda (Emeneau 1984; Spajić et al. 1996) and Kashmiri (Bhat 1987), which are both said to have palatalized retroflexes.

This section proceeds as follows. First, traditional definitions of palatalization as mere additional articulations are shown to be inadequate for coronal sounds. Then, to illustrate the change from retroflex to non-retroflex occurring with palatalization, the Russian retroflex fricative and its palatalized counterpart are discussed. In subsection 2.5.2, the alleged palatalized retroflex segments in Toda and Kashmiri are discussed and the status of these segments is analysed. Alternative descriptions for these supposedly palatalized retroflexes are proposed and it will be hypothesized that there are no counterexamples to the claim that secondary palatalization of retroflexion does not occur phonetically.

2.5.1 Palatalization as change in primary articulation

Palatalization in traditional articulatory terms is defined as the superimposition of an [i]-like gesture upon a labial, dental, alveolar, or post-alveolar consonant (cf. Ladefoged & Maddieson 1996). This superimposition of a gesture is undoubtedly the case for labials with a secondary palatalization, where the tongue dorsum gesture can take place independently and at the same time as the labial closing gesture. But for primary gestures with the tongue (either coronal or dorsal), the primary and secondary gestures are not independent of each other and therefore are expected to influence each other, which results in a change of the primary place of articulation. Support for this assumed change can be found in Ladefoged (1971: 207) who points out that "the terms palatalization and palatalized may also be used in a slightly different way from a secondary articulation, namely as describing a process in which the primary articulation is changed so that it becomes more palatal." Ladefoged & Maddieson (1996: 365) further specify this by stating that for all *coronal consonants*, secondary palatalization always involves a displacement of the surface of the tongue. This displacement is said to produce a slightly different primary constriction location (ibid.). We conclude from this that the traditional description of a secondary palatalization is inaccurate in the case of coronal segments, as this process always involves a change in the primary articulation for coronal sounds.

Articulatory evidence for a change of place in palatalized *apical dentals* is given in Scatton (1975) for Bulgarian, and Ćavar & Hamann (2002) for Polish. Hall (2000) argues that apical stops in general either turn into laminal stops when palatalized (in a synchronic or diachronic process) or resist palatalization.

For *retroflex segments*, it is proposed here that the addition of a palatalization gesture involves not only a change in primary articulation from apical to laminal but also in the articulatory class from retroflex to non-retroflex, since retroflexes not satisfying the criterion of apicality do not exist, see section 2.4.3. Support for this proposal can be found in Ladefoged (1971: 208), who mentions that the secondary articulations of palatalization, velarization, and pharyngealization involve different shapes of the tongue that cannot occur simultaneously. As velarization and pharyngealization were defined as realizations of the retroflex criterion 'retraction' in 2.3.4, Ladefoged's remark can be interpreted as an articulatory incompatibility of retroflexion and palatalization.

The incompatibility of gestures and the change in primary place is exemplified with the Russian fricatives in the post-alveolar region. Figure 2.13 is based on x-ray tracings of the Russian retroflex fricative (solid line) and its palatalized counterpart (dashed line) (both based on Bolla 1981: 159). As discussed before (see 2.4.2), the Russian retroflex fricative satisfies at least three of the four properties for retroflexion, namely apicality, sublingual cavity, and retraction, and is therefore assumed to be retroflex in this study (see also Hamann 2002b for a more detailed discussion of the Russian sound and its palatalized counterpart).

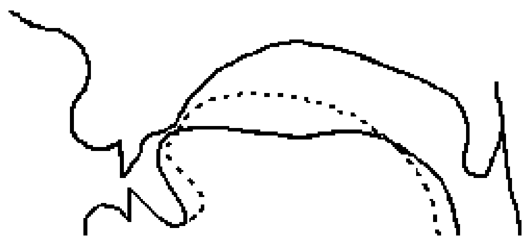

Figure 2.13 Russian retroflex fricative (solid line) and palatalized post-alveolar fricative (dashed line).

Comparing now the palatalized variant to the retroflex one, some major differences can be observed. First of all, the place of articulation changes for the palatalized segment; it moves further backwards to the post-alveolar region, which gives evidence for the assumed change in primary place of articulation for palatalized retroflex segments. Furthermore, the articulator is now the tongue blade, and the shape of the tongue middle changes to bunched and raised. The changes occurring for the palatalization of a retroflex are depicted in figure 2.14 with the four tongue parts as assumed already for a retroflex articulation in figure 2.10.

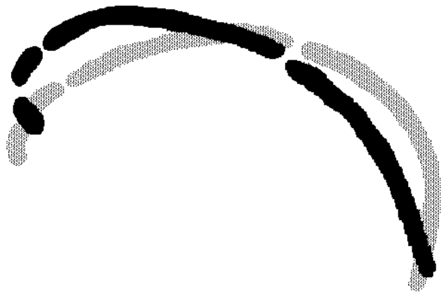

Figure 2.14 Palatalized ‘retroflex’, schematic movements of the tip, blade, middle, and back, underlyingly grey are the tongue parts at rest.

In terms of retroflex properties this means that the palatalized segment does not satisfy the properties of apicality and retraction, but only those of posteriority and sublingual cavity. As defined above in 2.3.5 und 2.4.3, a segment that has fewer than three retroflex properties does not belong to the category of retroflexes, thus the palatalized version of the retroflex fricative is claimed to be non-retroflex.

As palatalization in general involves the addition of or change towards an [i]-like gesture, and [i] and other front, high vowels are always articulated with a bunched tongue middle, this implies that secondary palatalization of retroflexes always results in a change in the property retraction from retracted to non-retracted articulation. But as apicality and posteriority without retraction is not possible (see implication in (8b)), a further change from apical to non-apical is necessary. The resulting segment satisfies the two properties of posteriority and sublingual cavity, and is according to (12d) not retroflex but a laminal post-alveolar. For the fricative [ʂ] the process of secondary palatalization thus results in the palato-alveolar fricative [ʃ], see (13a). The secondary palatalization of a retroflex stop and nasal is assumed to trigger similar changes, see (13b) and (13c), respectively.

(13) (a) [ʂʲ] = [ʃ]
(b) [ʈʲ] = [t̠] or [c]
(c) [ɳʲ] = [n̠] or [ɲ]

Hume’s (1994) observations on the palatalization of the post-alveolar fricative in Polish can be interpreted to support the claim made here. Hume follows the traditional descriptions of the Polish post-alveolar fricative and refers to it as post-alveolar [ʃ] instead of retroflex. Furthermore, she claims that the segment resulting from the palatalization process, i.e. [$ʃ^j$], is articulatorily identical to the laminal alveolo-palatal [ɕ].[24] Thus Hume describes the post-alveolar palatalization in Polish as in (14), which differs from the proposal made here in (13a).

(14) [$ʃ^j$] = [ɕ]

Though she does not explicitly mention a change in articulatory class, Hume's description of the segments indicates such a change. She refers to the palatalized sound with the features [–anterior, +distributed], which describe a laminal post-alveolar, and to the non-palatalized sound as [–anterior, –distributed], which is a retroflex segment in traditional featural accounts. Therefore Hume's description implies that the process of palatalization in Polish actually changes a retroflex fricative into a laminal post-alveolar, as stated in (13).

Besides the categorical change described above, another possible outcome of the secondary palatalization of retroflexes is to resist palatalization altogether, as pointed out by Hall (2000a). He gives an example from Scots Gaelic, where nouns usually undergo palatalization in the genitive singular: [$k^h at^h$] 'cat' (nom. sg.) surfaces as [$k^h at^{hj}$] (gen. sg.). Nouns with retroflex consonants, however, remain unpalatalized, e.g. [paːɽ] 'a poet' (both nom. and gen. sg.) (Borgstrøm 1940: 76). A resistance to palatalization is otherwise only reported for apical alveolars or dentals (e.g. Hall 2000a), which are also inherently retracted in some languages (recall 2.3.4). The property retraction can thus be made responsible for the blocking of palatalization, for the same articulatory reason that causes this property to change into non-retraction in secondarily palatalized retroflexes, namely articulatory incompatibility. It has to be tested whether the apical alveolars that show a resistance to palatalization are retracted and thus provide further evidence for the claim of articulatory incompatibility.

In sum, it was shown that retraction is incompatible with palatalization, which results in two possible outputs for retroflex palatalization, either a corresponding palatalized laminal, or a plain retroflex without palatalization.

2.5.2 Counterexamples: Toda and Kashmiri

According to Emeneau (1984), and Spajić et al. (1996) the Dravidian language Toda has palatalized counterparts of all its three rhotics, including the retroflex flap /ɽ/. Toda has minimal pairs such as [oɽ] 'to cook' vs. [$oɽ^j$] 'foot', or [toɽ] 'thigh' vs. [$toɽ^j$] 'pole used at funeral'. Interestingly, Spajić et al. could elicit retroflex rhotics and their palatalized counterparts only from some of their subjects; the three speakers of the Kas *mund* (a tribal location). The three speakers of the Melgas *mund* did not produce any of these forms. Sakthivel (1976, 1977) transcribes the palatalized retroflex rhotics, like all palatalized segments, with a sequence of rhotic

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[24] The only difference between the palatalized retroflex and the alveolo-palatal is, according to Hume, a secondary labialization of the palatalized sound, which the alveolo-palatal does not share.

(or other segment) plus palatal glide, indicating that the sounds in question consist of a sequence of two different articulations.

Though presenting a detailed phonetic study of the rhotics in question, Spajić et al. unfortunately do not include any palatographic or linguographic measurements of the palatalized flap /ɽ^{j}/ from which the exact articulation and the correlation of the gesture of retroflexion and that of palatalization can be judged.

Palatalized retroflex segments are also said to occur in the Indo-Aryan language Kashmiri (Bhat 1987: 43ff.). Kashmiri has the phonemes /ʈ^{j}, ʈ^{hj}, ɖ^{j}/. In Maddieson's phoneme inventory of Kashmiri (based on Kelkar & Trisal 1964), these segments are not included, the only retroflexes given there are the plain plosives /ʈ, ʈ^{h}, ɖ/. Morgenstierne (1941) proceeds similarly and does not mention palatalized retroflexes. The reason for this discrepancy in the description of the Kashmiri phoneme inventory is probably the class of the so-called *mātrā* vowels in Kashmiri. *Mātrā* vowels are extremely short (Maddieson 1986: 271 terms them 'overshort') or 'whispered' vowels (Masica 1991: 121). One of them is the $^{-i}$-*mātrā* which is said to leave a palatalizing effect on the preceding consonant. The assumption of this short /i/ vowel makes the statement of separate palatalized consonants redundant. Thus, in some descriptions of Kashmiri (e.g. Grierson 1911 and Morgenstierne 1941), the use of a retroflex segment with a following $^{-i}$-*mātrā* stands for what is described as palatalized retroflex in e.g. Bhat (1987). But this poses the question whether it is really a secondary palatalization of retroflexes that occurs in Kashmiri. These doubts are supported by Bailey (1937) who uses a retroflex plus a vowel /i/ in his transcriptions of Kashmiri in the place where the other researchers used either the $^{-i}$-*mātrā* or the palatalized consonant. In (15), a comparison of Grierson's and Bailey's transcriptions is given with the masculine singular forms of the adjective 'big'.

		Grierson	*Bailey*
(15)	NOM	boɖ^{u}	boɖ
	DAT	baɖis	bɜɖis
	AG	baɖ^{i}	bɜɖi
	ABL	baɖi	baɖi

As in the case of Toda, no articulatory data could be found for Kashmiri to illustrate the simultaneous combination of the retroflex and the palatalization gesture.

As the present study assumes that a simultaneous articulation of retroflexion and palatalization is impossible, the segments in these two languages have to be accounted for in another way. I propose that these segments are actually not retroflexes with a superimposed palatalized gesture, but sequences of a retroflex articulation followed by a short glide /j/. This proposal does not imply that the palatalized segment, which consists of two successive gestures, should be phonologically interpreted as two phonemes instead of one. I propose that Toda and Kashmiri are languages that chose to interpret the two gestures as belonging to one category. Only articulatorily do they make up two gestures.

Support for these separate gestures can be seen in the diachronic development of the alleged palatalized retroflexes in Kashmiri. Diachronically, the *mātrā* vowels in Kashmiri stem from vowels which have been shortened word-finally (Morgenstierne 1941: 89). Kashmiri hence had two separate gestures that were assigned to different phonemes, a consonantal and a vocalic one. These gestures were categorized at a later stage as belonging to one category (not consistently by every author, though, as we saw above). Furthermore, whereas the $^{-u}$- and $^{-\ddot{u}}$-*mātrās* (both causing velarization of the preceding consonant) are said to be inaudible nowadays (Morgenstierne 1941: 87), the $^{-i}$-*mātrā* still sounds like a very short [i], indicating a separate, additional i-gesture (ibid.).

Further evidence for the claim that there are two gestures instead of one may be found in the acoustic signal of the Toda trills. Spajić et al.'s (1996: 19) data of one speaker shows a difference between palatalized and non-palatalized retroflex trill: the duration of /ɽ^{j}/ is 190 ms and that of /ɽ/ only 100 ms. The palatalized version is thus nearly twice as long. There is no articulatory explanation why a palatalized segment should take longer to articulate than a non-palatalized one if one assumes that the two gestures co-occur. Assuming, however, that two gestures are produced successively, the nearly double length of the palatalized segment compared to the non-palatalized is explained.

In order to judge the values for palatalized and non-palatalized segment lengths, we will compare them to duration measurements (in ms) of the palatalized and non-palatalized segment pairs in Russian from Bolla (1981), see the tables 2.1, 2.2, and 2.3 below, giving the labial, velar and coronal (the latter tongue dependent) articulations, respectively.

Table 2.1 Duration measurements (in ms) of the plain and palatalized labials in Russian from Bolla (1981).

	p	b	f	v	m	ratio
plain	116	120	128	115	97	1
palatalized	170	140	130	125	97	1.14

Table 2.2 Duration measurements (in ms) of the plain and palatalized velars in Russian from Bolla (1981).

	k	g	x	ratio
plain	169	150	110	1
palatalized	184	160	120	1.08

Table 2.3 Duration measurements (in ms) of the plain and palatalized coronals in Russian from Bolla (1981).

	t	d	n	s	z	ratio
plain	134	102	105	195	96	1
palatalized	190	120	98	177	160	1.17

The average ratio between plain and palatalized segments in Russian is 1 : 1.12. The Toda retroflex rhotics have a ratio of 1 : 1.9 for plain vs. palatalized signal length, which is far higher than the Russian ratio. This difference sustains the claim made before that there might be two successive gestures involved in the articulation of the palatalized retroflex in Toda.

Unfortunately, we do not have any further measurements for palatalized rhotics, so the present data merely hint at the correctness of the hypothesis made here. Further research has to be conducted on the exact articulation and gestural timing of palatalized rhotics in general and palatalized retroflex in particular. This may shed light on the articulatory timing of the gestures and further properties of their articulation.

A formal account on how an articulatory sequence of retroflexion and palatalization can be phonologically interpreted as one segment will be given in section 6.3.3.5.

2.6 Summary and outlook

In this chapter, it has been shown that the class of retroflex consonants is one with enormous articulatory variation. This variation can be systematically accounted for by such parameters as speaker-dependence, context, manner of segment, language family, and inventory size.

Despite this large variation, there are some characteristics that can be found in nearly every instance of a retroflex. These properties have been defined as apicality, posteriority, sublingual cavity, and retraction. In order to belong to the retroflex class, a segment does not have to meet all four of these criteria: posteriority can be lacking. This is the case with the post-alveolar fricatives in Mandarin, which have traditionally been described as retroflex. It becomes obvious from this exception that a more restricted definition of retroflexion, one that requires all four articulatory properties to be present in a retroflex segment, would not include all segments traditionally described as retroflex. Because of this new definition, the non-posterior Polish and Russian fricatives had to be included into the retroflex class as well. We will see in chapter 4 that there is phonological evidence for such a wide definition, since all of the segments included here share some phonological behaviour. Furthermore, the broad definition of retroflex as applied here results in two retroflex fricative classes for Toda (see section 2.2.6). How this causes problems for traditional featural representations but can be dealt with in the featural approach I follow is a topic of chapter 5.

Apart from posteriority, it was shown that all other criteria have to be present in a segment to belong to the retroflex class. This was shown by the process of palatalization which causes a change towards non-apical and non-retracted articulation and thus from a retroflex to a non-retroflex segment.

Several sections of this chapter indicated topics that have to be further investigated. With respect to the variation of the retroflex class, the different reduction mechanisms of retroflex gestures applied in specific languages for instance could be studied; we saw in section 2.2.3 that Swedish retroflexes show fronting of the retroflex category in fast speech, whereas Hindi retroflexes show retraction in fast speech. On what factors do these reduction strategies depend, and do related languages show similar strategies? Another topic of retroflex variation mentioned in section 2.2.5 was the language-specific realizations of retroflex classes. Especially the sub-families of the Australian languages are worth investigating since traits might be found that are not shared by the large group of Australian families.

More important for the present study are additional studies on the allegedly palatalized retroflexes in Kashmiri and Toda, and evidence for their actual non-retroflex status in order to sustain the claim of non-existing palatalized retroflexes made here. In addition, other possible non-posterior retroflex fricatives should be tested, as for instance the Serbian post-alveolar fricatives as indicated by Keating (1991), to further attest that segments which lack the criterion of posteriority still behave phonetically and phonologically as retroflex. These issues I leave open for future research.

3 Acoustic cues and perceptual properties of retroflexes

Chapter 2 dealt with the fact that retroflexes of all manners can differ largely in their exact place of articulation and active articulator. Nevertheless, all retroflexes were shown to share three articulatory characteristics: raising of the tongue tip (apicality), a sublingual cavity, and retraction of the tongue body. In addition to that, all retroflex segments apart from some fricatives have the characteristic of posterior place of articulation (posteriority). The present chapter deals with the question of whether the phonological class sharing these articulatory properties also has some acoustic properties in common. In order to give an answer to this question, the acoustic correlates of the four articulatory properties are described and compared to the acoustic cues of retroflexes in natural languages. It will be shown that all retroflexes have a lowered third formant and often a raised second formant, as can be predicted from the articulatory characteristics, in addition to their manner-specific cues. The second and third formant cues will be compared to cues of other places of articulation (both coronal and non-coronal), to determine the extent to which they refer exclusively to this class and hence are sufficient to define retroflexion. A special section deals with the context dependency of retroflex cues and the resulting variation. Furthermore, the asymmetrical spread of cues for a retroflex place of articulation is discussed. It will be checked whether the cues hold only for retroflexes in specific positions where these cues are more salient, or are context-free. Retroflexion belongs to the so-called ‘weak’ acoustic cues according to Stevens & Keyser (1989) (see the discussion of weak features in section 1.2), who furthermore claim that these weak cues can be enhanced by certain articulatory additions such as rounding or velarization. The insufficiency of the notions ‘cue weakness’ and ‘cue enhancement’ with respect to retroflexes will be demonstrated. Finally, the question will be discussed why the acoustic cues of retroflexion and palatalization are incompatible, supporting the same claim made on articulatory grounds in chapter 2.

This chapter is structured in the following way. In 3.1 a short description is given of the type of cues that are necessary for the description of articulations across different manners. This is followed by section 3.2 on the acoustic characteristics of retroflexion to be expected from their articulatory properties stated in chapter 2, and is subdivided into sections on apicality, posteriority, sublingual cavity and retraction (sections 3.2.1 – 3.2.4, respectively). Section 3.3 looks at the cues of retroflexes found in natural languages and compares them to the predictions made in the previous section. This part is subdivided into sections on formant frequencies (section 3.3.1), which deals primarily with stops but also nasals and liquids, and spectral cues (section 3.3.2). The latter is mainly concerned with fricative spectra, and deals with the question whether Mandarin, Slavic, and Toda post-alveolars are retroflex from an acoustical point of view (subsections 3.3.2.1 and 3.3.2.2). In section 3.4, the vowel-dependency of retroflex acoustic cues is discussed, and section 3.5 elaborates on the asymmetrical behaviour of retroflex cues. This includes the results of a perception test I conducted using Norwegian retroflex and dental segments. Section 3.6 contains a discussion on the usefulness of the notion of weak cues and cue-enhancement for retroflexion. In 3.7, the incompatibility of the acoustic cues of retroflexion and palatalization are described. Section 3.8 is a summary of the main findings.

3.1 Acoustic cues used for the description of retroflexes

In order to be able to describe the acoustic cues for retroflexion, it first has to be determined which cues are relevant for the distinction among places of articulation for consonants. In general, there are two kinds of acoustic information available, namely static and dynamic. Static information is given for instance by short-term spectra of the signal, which illustrate the energy spread of a signal for a specific point in time. Dynamic information is given for instance by formant transitions, which track the change of vocal tract resonances from preceding and following vowels into the consonant. Any kind of temporal changes in the acoustic signal is dynamic. Whether dynamic or static information is needed by the speaker to detect a specific place of articulation depends partly on the manner of articulation. All kinds of speech signals with irregular noise patterns such as fricatives or the burst noise of a plosive can best be captured by spectral information. But whereas for example short time spectral analyses (STS) are sufficient for the correct perception of fricatives, plosives cannot be detected on the basis of STS alone, as Walley & Carrell (1983) showed in their perception tests. They confronted listeners with STS and formant transition stimuli and found that the cues given by STS are not sufficient for detecting the place of articulation for stops; the listener needs further information on the change over time in the form of formant transitions. A similar result was obtained by Lahiri et al. (1984), who showed that the STS of an alveolar stop is very similar to that of a labial, and listeners therefore tend to confuse the two.

A perception test by Stevens & Blumstein (1975) for Hindi speakers, on the other hand, attested that for plosives the formant frequencies were not sufficient but that the burst has to be added to obtain consistent retroflex responses. The same result was obtained by Ohala & Ohala's (2001) perception test of Hindi plosives. The correct classification for retroflexes and dentals in their test dropped from an average of 84.9 percent to 66.4 percent when the release was not present in the signal. Thus, static information (burst) or dynamic information (transitions) alone do not seem to be sufficient for a correct recognition of the place of articulation for a stop: both types of information are necessary.[1]

Besides information on the distribution and change of distribution of energy, durational cues are also important for the distinction of place contrasts. Ladefoged &

[1] Information obtained from such perception tests is not consistent, however. Winitz, Scheib & Reeds (1972) found that listeners are very well capable of classifying the place of articulation correctly when presented with the burst of the stop alone, without any information about the formant transitions.

Maddieson (1996: 30) refer in their description of the four coronal stops of Eastern Arrernte to the closure duration and to the voice onset time (VOT) to distinguish all four segments.

The following sections of this chapter look both at static cues of retroflexion in the form of spectral shapes and at cues that describe the change over time in the form of formant transitions leading into and out of retroflex consonants. The first formant (F1) will be ignored in the following descriptions, as it is lowered into the segment for any kind of constriction in the vocal tract (Lindblom & Sundberg 1971), and the release of this constriction is always accompanied by an increase in F1 (Stevens 1998). Instead, the present study will focus on the transition of the second and third formants (F2 and F3). Durational cues such as VOT or closure duration will not be treated separately but referred to whenever relevant.

3.2 Acoustic realizations of the articulatory properties of retroflexes

In chapter 4, four articulatory properties were used to define the class of retroflex segments, namely apicality, posteriority, sublingual cavity, and retraction. The present section describes the acoustic realizations of these four articulatory characteristics (subsections 3.2.1 – 3.2.4) as predicted from acoustic modelling and as found in language-specific speech sounds with such characteristics. Subsection 3.2.5 summarizes the acoustic effects of all four properties and serves as a prediction to be compared to the acoustics of retroflex segments in natural languages as discussed in the sections after that (3.-1 - 3.7).

3.2.1 Apicality

Stevens (1996) and Ohala & Ohala (2001), among others, have stated that coronal articulations, i.e. articulations with the tongue tip or blade, generally result in a raised F2. Apical articulations, though, show a lower F2 than laminals (Dart 1991). Hamilton (1996: 47) found that both apical series in Australian languages have very similar F2 attributes, which are lower than those of the laminals in the studies he consulted.[2] A similar observation was made by Shalev et al. (1993) for Toda. The difference between apicals and laminals has been associated with differing tongue body positions behind the constriction; laminals are assumed to have higher F2 values because their tongue body is in a higher position than for apicals (Dart 1991: 63). The exact position of the tongue body depends largely on the vowel context the segments occur in; thus, the F2 transition is very much vowel dependent, as pointed out by for instance Stevens & Blumstein (1975: 219). A detailed description of the effect of the vowel contexts on the formant transitions of retroflexes will be given in section 3.4.

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[2] Hamilton bases his observations on the studies by Busby (1979) on several Australian languages, McGregor (1990) on Gooniyandi, Evans (1985) on Kayardild, Bradley (1980) on Yanyuwa, and McDonald (1977) on Yaraldi.

A more reliable cue than the F2 transitions for distinguishing apicals from laminals seems to be the duration of the transitions. Stevens et al. (1986: 432) point out that an apical movement can be achieved much quicker than a laminal one. Formant transitions of apicals are thus shorter than those of other consonants. Furthermore, the quickness of the apical gesture results in a more abrupt onset for an apical release compared to a laminal release.

Besides the distinction by form and duration of transitions, apicals can be differentiated by their spectral shape. The spectra of apical sounds show a strong mid-frequency peak, in contrast to laminals, which have monotonously decreasing spectra with increasing frequency, as Ladefoged & Maddieson (1996: 30) illustrate for Eastern Arrernte.

3.2.2 Posteriority

The criterion of posteriority holds for retroflexes as well as for palato-alveolars and alveolo-palatals, because all three articulations are coronal and non-anterior, since all are articulated behind the alveolar region.

The acoustic equivalent of posteriority cannot be treated independently from the articulatory criterion sublingual cavity, as a coronal posterior articulation automatically produces a cavity under the tongue due to the tongue tip or blade displacement (see implication (8a) in chapter 2). The exact acoustic consequences of the joint characteristics posteriority and sublingual cavity will therefore be described in section 3.2.3 below.

It is interesting to note the effects of a shift in posteriority in articulatorily synthesized speech. Narayanan & Kaun (1999) found that moving the place of constriction further backwards for a coronal lateral results in a lowered F3, whereas the forward movement from a post-alveolar place of articulation (from retroflex to alveolar) results in an increase in F3. From this it can be assumed that retroflex posterior articulations in natural languages probably show some difference in F3 from laminal posterior articulations (though we cannot be sure about the direction yet). Furthermore, the two types of retroflexes as distinguished in chapter 2, one satisfying all four articulatory properties, the other lacking posteriority, might show a difference in the acoustic signal in the degree of F3 lowering: a non-posterior retroflex should have a less low F3 than a retroflex articulated more back. This hypothesis was not tested in the present study, since the exact articulation of retroflexes in natural speech is expected to differ in more than the property of posteriority. Other articulatory properties that can vary in retroflexes (though not to a degree that their retroflex status is at stake) are the size of the sublingual cavity (see 3.2.3), the degree of tongue retraction (as described in 3.2.4 below), and additional lip-rounding, all affecting the acoustic signal. To actively control these parameters in natural language in an experiment was beyond the scope of the present dissertation but is obviously a topic for future research.

3.2.3 Sublingual cavity

The presence of a sublingual cavity has the same effect as a posterior coronal articulation; both add length to the front cavity of the vocal tract, and thus lower its resonance frequencies (Johnson 1997: 119). Again, retroflexes, palato-alveolars, and alveolo-palatals share this property. The difference between a palato-alveolar and a retroflex lies in the size of the sublingual cavity, which increases the further back the tongue tip or blade closure is located (Sundberg & Lindblom 1990: 1313). In addition, the size of the cavity is partly vowel-dependent, with back vowels allowing a bigger cavity than front vowels.

For retroflex *laterals*, Stevens (1998) states that a sublingual cavity has two acoustic effects, namely the introduction of a low-frequency resonance F_R and the introduction of a zero Z_R. The F_R is located between F2 and F3, at approximately 1800 Hz and is therefore often associated with the F3 of the adjacent vowel (Stevens et al. 1986: 436). This resonance frequency does not form a separate, distinguishable formant during the constriction, but results in a greater bandwidth of F2 or a replacement of F3, which is possible as the F3 is weak during closure of the consonant. F_R is therefore sometimes interpreted as a low frequency F3 of the lateral consonant.

The zero Z_R introduced via the sublingual cavity is located around 2000 Hz, but as Stevens (1998) points out, the exact trajectories of F_R and Z_R show considerable variability cross-linguistically (depending on such factors as elaborated in chapter 2). The effect of Z_R is a weakening of the amplitude of F3 and higher formants. F_R and Z_R are depicted schematically in figure 3.1, together with the trajectories of the first three formants of a retroflex lateral.

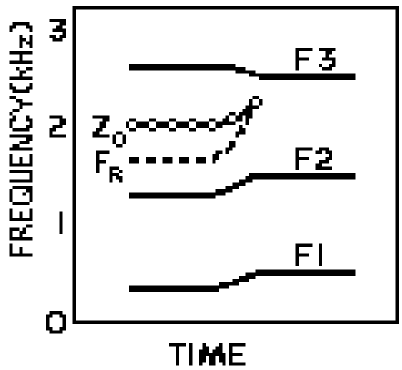

Figure 3.1 Language-independent schema of F1, F2 and F3 trajectories for a lateral retroflex released into a vowel (Stevens 1998: 538).

At the release of the retroflex closure, F_R and Z_R merge, which results in an increase in the amplitude of F3, F4, and F5 (Stevens 1998). In sum, the additional formant and the zero introduced by the sublingual cavity are interpreted as a high second formant (in cases where F_R is associated with F2) and low third and higher formants (due to Z_R) during the consonant constriction. The transitions into the following vowel are therefore a falling F2 and a rising F3. A larger sublingual cavity, for instance in palatal retroflexes or in retroflexes in a back vowel context, results in a lower F3 than for the average retroflex.

These generalizations hold for all retroflex consonants that show continuous formant structure during the consonant, such as laterals, rhotics, and nasals. For stops, parts of the formant trajectories are not observable, due to the closure silence and the stop burst.

Shalev et al. (1993: 117) point out that lowered F3 and F4 values are not restricted to retroflexes but hold for all apicals, as apical alveolars also have a sublingual cavity, though it is considerably smaller (recall discussion in 4.3.3). Dart (1991) confirms this for languages that contrast apical and laminal articulations, e.g. the Amerindian language ’O’odham and the Dravidian language Malayalam: in these languages the apical series have lower F3 and F4 than the laminals.

3.2.4 Retraction

As defined in section 4.3.4, the articulatory characteristic of retraction (or ‘tongue backing’) subsumes the secondary articulations of velarization and pharyngealization. An indication for their acoustic and auditory similarity can be found in Laver (1994: 327), who states that pharyngealization gives a similar auditory effect as velarization; “Like velarization, pharyngealization is often described impressionistically as imparting a ‘dark’ quality to segments” (ibid.).

Velarization is usually correlated with a lowered F2. In Marshallese, for example, the second spectral peak of the velarized nasal is low (Ladefoged & Maddieson 1996: 361). Brosnahan & Malmberg (1970: 67) add that velarization also involves a slight lowering of F3 besides considerable lowering of the frequency of F2. Pharyngealization, the second articulation subsumed under retraction, is also described as causing a distinct lowering of F2 (Stevens 1998: 365). Ohala (1985) mentions that the lowered F2 explains why velarization is not perceivable on segments that have a lowering of F2 anyway, such as labials or back vowels. Ohala’s observation can be extended to apicals, which were shown above in 3.2.1 to have a lower F2 than laminals. The non-perceptibility of velarization in lower F2 segments might explain why retroflexes are usually not perceived and thus not described as having distinct velarization or pharyngealization.

3.2.5 Summary of acoustic consequences

In 3.2.1 – 3.2.4 the realizations of the four articulatory criteria of retroflexion were discussed. It is clear from these descriptions that it is difficult if not impossible to ascribe a specific acoustic effect to a single articulatory property, as the interaction of sublingual cavity and posteriority illustrated. Summing up, apicals have a lower F2 than laminals, but still a higher F2 than non-coronals, in order to indicate a coronal articulation. Both posteriority and sublingual cavity cause a rising of F2 and a lowering of F3, and retraction causes a lowering of F2 and F3. A retroflex consonant is therefore expected to show a lowered F3. For F2, both raising and lowering occur, but as raising is predicted by three properties, and lowering only by one, we expect the second formant for a retroflex to be raised or to be neither raised nor lowered, probably depending strongly on the vowel context.

Whether these cues are actually present in retroflex consonants, i.e., whether the articulatory defining criteria developed in chapter 2 are realized in the respective cues in natural languages, will be discussed in the following section.

3.3 Cues of retroflex consonants

In this section, the acoustic properties of retroflexes in natural languages will be analysed. This description is subdivided according to the type of cues into formant transitions and spectral shape. These cues are compared to the acoustic realizations predicted on the basis of the articulatory characteristics of retroflexes, namely low F3 and high or mid values for F2. Section 3.3.1 on formant transitions is primarily concerned with retroflex stops, but also describes the formant transitions of retroflex laterals, rhotics and nasals. Furthermore, a comparison of retroflex transitions to those of other coronals and to non-coronals will be given in this section. Section 3.3.2 on spectral shape is restricted to fricative spectra. It specifically deals with the question of what acoustic cues are characteristic for a retroflex fricative. 3.3.2 consists of three subsections in which the retroflex fricative cues are compared with the acoustics of post-alveolar fricatives in Polish, Mandarin, and Toda, respectively. It is shown that they all share a low F3, and thus support the hypothesis postulated in chapter 2 that these segments can be considered retroflex. Additional cues are discussed briefly in section 3.3.3, especially in view of the question of how to distinguish coronal articulations in general.

3.3.1 Formant frequencies

This section deals with the trajectories of F2 and F3 in retroflex stops and other manners.[3] The second formant of retroflexes in natural languages shows considerable variation. Stevens & Blumstein (1975: 219) state that F2 is the same for retroflex and non-retroflex consonants, as this formant is associated with tongue body movement and therefore largely depends on the vowel context, which is in line with the predictions made on the basis of the articulatory characteristics above. However, Ohala & Ohala (2001) found in their investigation of Hindi stops that retroflexes show a convergence of F2 and F3 in all vocalic environments, whereas Dart & Nihalani (1999) found that the retroflex stops and nasals in Malayalam are generally characterized by a low F2. From this, one can assume that the height of F2 might be partly language-dependent in addition to such factors as vowel context. Further in-

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[3] The description of formant transitions with the help of locus equations and studies on locus equations of retroflexes, e.g. Sussman et al. (1993), are ignored here. This method might yield acoustic information on co-articulation, but this information on the place of articulation is not invariant (Fowler 1994).

formation on the variability of F2 and the vowel dependency of this cue is given in subsection 3.4 below.

Concerning the third formant, the articulatory characteristics in section 3.2 predicted a lowering from the vowel to the consonant and a raising from the consonant constriction to the vowel. This is in accordance with the descriptions of the class of retroflexes in natural languages. Retroflexion is said to affect mainly higher formants, which are generally lowered (e.g. Ladefoged 1971: 180 or Ladefoged and Maddieson 1996: 27). Stevens & Blumstein (1975) state that specifically the third formant shows a characteristic lowering for retroflexes. This observation is attested by language-specific investigations of retroflexes. Hamilton (1996: 47) illustrates in his investigation of Australian languages that a lowered F3 is the most distinctive acoustic feature of retroflexion. Similarly, both the study by Shalev et al. (1993) on Toda stops and the one by Dart & Nihalany (1999) on Malayalam stops (and nasals) show that the retroflexes have the lowest F3 of all coronals.

The low F3 for retroflexes can also be shown to hold for other manners of articulation than stops. Ladefoged and Maddieson (1996) for example state that the retracted rhotic trill in Malayalam has a lowered third formant (p. 222) and that the retroflex articulation of the rhotic in American English[4] also shows a low F3 (p. 234). Spajić et al. (1996) investigated the trills of Toda, and found that the retroflex rhotic is distinguished from the dental and alveolar by a lower F3 (and a lower F4). The formant frequencies of Tamil liquids, as measured by Narayanan & Kaun (1999), show that the lateral retroflex [ɭ] has a F3 – F2 difference of 573 Hz versus 1360 Hz for the lateral alveolar [l], indicating a lowered F3 for the retroflex.[5]

Stevens & Blumstein (1975: 219) describe retroflexion as showing a clustering of F3 and F4 in a relatively narrow frequency region. Fant (1968) observes that retroflexion results in the F4 coming down to F3, which is lowered as well. Thus, there is general consensus on the retroflex property of low F3, which is in accordance with the acoustic predictions of the articulatory characteristics of chapter 2.

In sum, only one stable acoustic characteristic for retroflexion in the formant transitions can be manifested, namely a lowered F3, since the F2 seems largely context-dependent. Hamilton (1996) claims that the lowered trajectory of F3 is what actually distinguishes retroflexes from other coronals. Whether this is really the case can be tested by looking at frequency values of the second and third formants in languages with a four-way coronal contrast. The following tables illustrate such data: table 3.1 gives the average values of stop loci in Gooniyandi based on McGregor (1990: 56), and table 3.2 the average nasal and lateral coronals formants for several Australian languages based on Busby (1979: 163 and 161, respectively). When

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[4] The retroflex articulation of American English *r* exists in addition to several other articulations, cf. Hagiwara's (1995) study. Interestingly, Hagiwara points out that a lowering of F3 can be achieved by three strategies: a constriction of the lips, in the pharynx, or somewhere in the oral cavity around the velum (p.12), see the discussion of enhancing cues in section 3.6.

[5] Narayanan & Kaun's study (1999) further shows that there are differences in the actual F3 even within the class of retroflex liquids. Whereas the lateral [ɭ] had an average F3 value of 2321 Hz, the rhotic [ɽ] had an average F3 value of 2082 Hz only. This might be due to manner-specific differences in the formant trajectories.

comparing the data in the two tables it has to be kept in mind that stop loci are a different kind of information than formants: loci are the assumed frequency of formants when tracing them backwards, i.e. before the stop burst. Thus, stop loci have more extreme formant values than continuing formant trajectories of sonorants.

Table 3.1 Stop loci averages for Gooniyandi (McGregor 1990: 56).

	t̪	t	ʈ	t̠
F2	1600	1750	1600	2200
F3	2500	2750	1800	3000

Table 3.2 Coronal nasal and lateral formants averaged over several Australian languages (Busby 1979: 163 and 161, respectively).

	n̪	n	ɳ	ɲ	l̪	l	ɭ	ʎ
F2	1654	1502	1735	2156	1611	1509	1493	2009
F3	2499	2279	2129	2936	2589	2632	2377	2900

For all three classes, the retroflex has by far the lowest F3, though the actual value is lower for the stop loci (1800 Hz) than for the nasal (2129 Hz) or the lateral formants (2377 Hz). The formant frequencies of F2 do not show invariant patterns. For the stops in table 3.1, the retroflex F2 has the same locus as the dental, and both are lower than the alveolar or palato-alveolar. The nasal retroflex in table 3.2 has F2 values that lie between apical alveolar and palato-alveolar. Still another ordering emerges from the second formants of the laterals in table 3.2, in which the retroflex has lowest values. These data are averaged across different vowel contexts, which might account for these large differences. The language-specific data henceforth confirm the statement made above that only a low F3 is a reliable and context-independent cue for a retroflex place of articulation.

Let us look briefly at the difference between the remaining coronals. Comparing the formant frequencies of all four coronal places, the laminal post-alveolar articulation has the most distinctive formant transitions, namely high F2 and high F3.[6] The apical alveolar and laminal dental cannot be easily distinguished on the basis of F2 and F3 trajectories alone. Whereas in Busby's data on nasals and laterals (see table 3.2) the apical alveolar has a lower F2 value than the laminal dental, McGregor's data for Gooniyandi stops (see table 3.1) show a higher value for the apical alveolar locus. Concerning the third formant, the values for the apical alveolar are lower than that of the laminal dental in the averaged data by Busby, the reverse relation holds for McGregor's data of Gooniyandi stop loci. The similarity in formant transitions for these two segment classes is shown also by Bradley (1980) for Yanyuwa and by

6 The laminal postalveolars in Malayalam (Dart & Nihalani 1999) seem to depart from the general pattern of a high F3 for palato-alveolars, as these sounds show a low F3 and high F2, i.e. a convergence of both formants. Dart & Nihalani (1999: 138f.) provide a possible explanation for this behaviour: the Malayalam post-alveolars might have a higher tongue position behind the constriction than the average post-alveolar, which could account for the high F2.

Evans (1985) for Kayardild. According to Hamilton (1996: 49) the formant transitions of the two classes are essentially identical. Other cues like the duration of the segments, duration of adjacent vowels, voicing, and spectral properties of the burst are necessary to distinguish laminal dentals from apical alveolars, see section 3.3.3 below.

Is the property of low F3 sufficient to distinguish the retroflex articulation also from non-coronal consonants? Let us look at data that compare retroflexes to labials and velars. Table 3.3 gives the results of Busby's (1979: 163) measurements of nasal formants, and table 3.4 those of McGregor's (1990: 56) measurements of stop loci. In the latter, a subdivision is made between velars with following front versus velars with following back vowel.

Table 3.3 Nasal formants averaged over several Australian languages (based on Busby 1979: 163)

	m	ɳ	ŋ
F2	1285	1735	1441
F3	2211	2129	2215

Table 3.4 Stop loci averages for Gooniyandi (McGregor 1990: 56)

	p	ʈ	ki	ku
F2	1000	1600	1500	750
F3	2500	1800	2000	–

For the labial, retroflex, and velar nasals in table 3.3, the values of the third formant are all very close together, around 2200 Hz, with the retroflex slightly lower. The difference in F2 values is more prominent, since the retroflex value is much higher than that of the other two places of articulation (on average 372 Hz). This is in accordance with Stevens (1996) and Ohala & Ohala's (2001) observation that coronal articulations generally have a higher F2 than non-coronals. A similar tendency can be found in table 3.4, where the F2 locus of the retroflex stop is higher than that of the other articulations, though only 100 Hz higher than that of the velar in front vowel context. The F3 value of the retroflex stop locus is lower than that of velar and labial, but again rather close to the velar in the front vowel context. This similarity between retroflex formant cues and formant cues of velars in front vowel context has been also observed by Ohala & Ohala (2001: 273) in their measurements of Hindi consonants. Nevertheless, their perception test (results are presented in 3.4) did not show any misclassification of retroflex as velar or vice versa in high front vowel context (for Hindi; the Dravidian or Australian apico-palatals could be very in this respect). Table 3.5 sums up the formant values of retroflexes compared to other coronal and non-coronal articulations.

Table 3.5 Height of formant frequencies in comparison to each other as concluded from the information in table 3.1 – table 3.4 (stop symbols are taken exemplarily, these generalizations are not meant to be restricted to stops).

	b	t̪	t	ʈ	t̠	k
F2	mid	high	high	high	highest	low
F3	low	mid	mid	lowest	highest	low

Altogether, a low F3 is sufficient to distinguish retroflexes from other coronals. This cue might be adequate for a distinction between retroflex and non-coronal places of articulation, though an additional specification as high F2 (indicating a coronal articulation) improves the distinguishability. Furthermore, the perceptual salience of F3 can be very much enhanced by having it coalesce with F2 into a single peak (see Stevens 1998: 238ff. for a similar observation on vowel formants).

3.3.2 Spectral shape

The shape of the spectrum is another way of describing the acoustic difference between the places of articulation. Spectral information is of use in cases where formant trajectories are not easily detectable, for instance in fricative signals. Though formant transitions for fricative consonants are similar to those for plosives with the same place of articulation, Stevens (1996: 484) points out that the transitions for fricatives tend to be less extreme. Spectral information might therefore be more useful than vowel transitions for classifying fricatives. Furthermore, the spectral shape is sometimes used for phonological classification. For example Jakobson, Fant & Halle (1952) use short time spectral analyses (STS), which are measured at the moment of burst release (Stevens & Blumstein 1975), for a classification of stops, and introduce phonological features based on this information. The correlates of Jakobson et al.'s features are mentioned below, when the features themselves will be discussed in chapter 5. Before describing spectral shapes in detail, it has to be pointed out that spectra vary considerably from speaker to speaker, and thus a cross-speaker comparison is often of limited use, see for instance to Shadle et al. (1992) on fricatives in general and Lindblad (1980) on Swedish fricatives.

Coronals in general have an energy distribution across the whole spectrum, with at least two peaks between 1200 and 3600 Hz. Jakobson et al. express this with the feature [diffuse]. The class of coronals shares this property with labials, but in contrast to labials the coronals have a rising shape of spectrum ([acute] in Jakobson et al.'s terms). Laminals are distinguished from apicals by showing a monotonic decrease of amplitude as the frequency increases, whereas apicals have a more abrupt decrease. This results in a more spread spectral energy for laminals than for apicals. Apicals in general show a strong mid-frequency peak (Ladefoged & Maddieson 1996). This peak is narrower for retroflexes, and hence the spectrum of a retroflex is less spread than that of an apical alveolar (Fant 1974: 138). Jakobson et al. use the feature [flat] to describe this downward shift or weakening of the upper frequency components of retroflexes. Lip rounding, velarization, and pharyngealization have the same acoustic effect of ‘flatness’.

Dart & Nihalani (1999: 139) measured the stop burst spectra for Malayalam coronals, which illustrate the observations on coronal spectra made here. The spectrum of the Malayalam retroflex fricative has more energy in the lower frequencies (below 2 kHz) and drops off above 4000 Hz. The dental shows slightly higher energy spread (between 2.5 and 3.5 kHz). The alveolar and the palato-alveolar show considerably higher energy, with the palato-alveolar having an energy concentration between 4-5 kHz, and the alveolar having a flat spectrum.

The concentration of energy in the lower frequency is hence a distinguishing criterion for retroflex fricatives. Stevens & Blumstein (1975) point out that the frication noise for retroflex obstruents also starts lower than for their non-retroflex equivalents. This is observable in the Malayalam case and also in Ladefoged and Maddieson’s (1996: 163) description of the four places for coronal fricatives in the Caucasian language Ubykh. The retroflex fricative in Ubykh has the lowest frequency of all the sibilants found in this language. As this sound is less retroflexed (i.e. satisfies only the articulatory characteristics apicality, sublingual cavity, and velarization, but not posteriority) than for example the Toda subapical palatal fricative,[7] it indicates that any kind of retroflex fricative has a very low frequency start.

Shalev, Ladefoged & Bhaskararao (1993) associate the first peak of frication noise with the third formant of adjacent vowels, thus a low start of frication noise and a low first peak in a fricative spectrum are equivalent to a low F3 in a vowel and and can be treated as the same acoustic criterion for retroflexion: where retroflex vowels and vowel transitions of a retroflex consonants show a low F3 (which is often enhanced by a high F2), the retroflex fricative shows a first, high-amplitude peak at roughly the same frequency as this F3.

It has to be added that not all retroflex fricative spectra have the lowest start of friction noise and the lowest first peak compared to other coronals articulated by the same speaker. For example Lindblad’s (1980) study on Swedish sibilant fricatives based on his own pronunciation shows some irregularity in this respect. The palato-alveolar [ʃ] in this study has a lower first peak and start of the friction noise than the retroflex [s̢], the difference amounting to roughly 500 Hz. Two possible explanations can be given for the lower first peak in [ʃ]. First, the sounds might have been recorded in different vowel context, namely the palato-alveolar in a more back vowel context than the retroflex, resulting in a larger sublingual cavity and thus lower first peak (i.e. lower F3). Second, the retroflex in Swedish is non-posterior (i.e. fulfils only three articulatory characteristics of retroflexion), and thus has a smaller sublingual cavity as the palato-alveolar, which results in a higher first peak than for the palato-alveolar. As no information on the exact articulation and context of these segments is given, we cannot explain at this point why Lindblad’s data depart from the general tendency of lowest friction noise for retroflexes.

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7 Ladefoged and Maddieson transcribe the Ubykh retroflex as [s̢] because its articulation lacks a bent-backwards tongue tip.

3.3.2.1 Mandarin apical post-alveolar fricatives

Chapter 2 and especially subsection 2.2.4.3 already addressed the extent to which the Mandarin post-alveolar fricatives can be called retroflex, as these sounds do not show any bending backwards of the tongue tip but instead a flat tongue middle. In this section we will compare the acoustic characteristics of these sounds to those of retroflexion developed above. Lee (1999) measured the frequency ranges of the spectral energy of the sibilants [s, ts, ɕ, tɕ, ʂ̺, tʂ̺][8] in Beijing Mandarin. This investigation involved two female and two male speakers, table 3.6 gives the mean values (in kHz) for both groups.

Table 3.6 Frequency ranges (in kHz) of the spectral energy of Mandarin sibilants (Lee 1999: 416).

	s	ts	ɕ	tɕ	ʂ̺	tʂ̺
Female	7 – 14	6.5 – 13.5	4 – 11.5	3.5 – 11	2 – 10	2 – 10
Male	4.5 – 10.5	4.5 – 9	3 – 9.5	3 – 8.5	2 – 7.5	2 – 7

Comparing the apical, retroflex, and alveolo-palatal fricatives, the retroflex series has the lowest frequency range, around 2 kHz for both male and female speakers. This is in accordance with the criterion of low frequency start for retroflex frication noise given in 3.3.2 above. Unfortunately, no description or data on the shape of the fricative spectra is given by Lee, thus a further comparison to typically retroflex spectral shapes cannot be made. But as the findings conforn to traditional (e.g. Chao 1948; 1968) and recent descriptions (Ladefoged & Wu 1984 and Ladefoged & Maddieson 1996) of the Mandarin post-alveolars as retroflex, this does not seem necessary.[9]

3.3.2.2 Polish post-alveolar fricatives

Similar to the Mandarin sounds, the Polish post-alveolar apical fricatives have been claimed by some authors (e.g. Keating 1991, Hall 1997a) to be retroflex, though the traditional Slavic literature does not apply the term retroflex to these segments. Articulatory reasons for treating these sounds as retroflex were discussed in section 4.4.1.

Halle & Stevens (1997) compare the acoustics of the Polish post-alveolars [ʂ̺, ɕ][10] by measuring the two major spectral peaks for each segment in the frequency range 2 – 4 kHz. Halle & Stevens associate these two peaks with F3 and F4 because they seem to be contiguous with the third and fourth formants of the adjacent vowels. The values (in Hz) for the major peaks, split according to speakers' gender, are given in table 3.7.

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8 The aspirated retroflex and palatal affricates were not a topic of Lee's study.
9 It has to be pointed out, however, that Lee (1999) does not classify the Mandarin post-alveolars as retroflex because they do not show any curling backwards of the tongue tip.
10 The symbols used here differ from Halle & Stevens's symbols, who transcribe the retroflex fricative as an alveolar fricative with a subscript dot.

Table 3.7 Average frequencies of the two major lower peaks of the Polish fricatives [ʂ] and [ɕ] (from Halle & Stevens 1997: 182).

	ʂ		ɕ	
	Female	Male	Female	Male
F3	2590	2470	2480	2520
F4	3510	3100	3490	3150

The values for both sounds are extremely close together and the retroflex does not show a generally lower F3. In addition to these measurements, Halle & Stevens give some additional descriptions of the spectral shape of these two sounds. The F3 prominence of the retroflex is narrower than for the alveolo-palatal, and the spectrum amplitude decreases more rapidly for the retroflex, both characteristics being in accordance with the spectral shape of retroflex sounds as established above.

Dogil (1990) reproduced Halle & Stevens' study; his findings are summarized in table 3.7.[11]

Table 3.8 Average frequencies of the first three peaks for the Polish fricatives [ʂ] and [ɕ] (Dogil 1990: 49ff.).

	ʂ		ɕ	
	Female	Male	Female	Male
F2	1365	1265	–	–
F3	2685	2560	3055	2695
F4	2995	2910	3560	3280

In Dogil's data, the lower F3 for the retroflex fricative is clearly detectable. Comparing these to Halle & Stevens's data in table 3.7, it becomes obvious that the two studies do not differ in F3 values of the retroflex, but in that of the alveolo-palatal. Halle & Stevens did not find a lower F3 for retroflexes, because the F3 values for their alveolo-palatals were unusual low. I cannot provide an explanation for this deviation, other than that the alveolo-palatals might have been rounded or in a rounded context.

Summing up, the acoustic data supports the claim made in chapter 2 that the apical post-alveolar fricative in Polish is a retroflex. For phonological evidence of this point, see chapter 4.

3.3.2.3 Toda apical post-alveolar sibilants

The Toda fricative system poses a somewhat different question than that of Mandarin or Polish. As we saw in section 2.2.4.2, Toda is the only Dravidian language with

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[11] In contrast to Halle & Stevens, Dogil included the allophone [ʃʲ] in his measurements, though the values for this segment are not reproduced here. Furthermore, Dogil investigated both voice and voiceless retroflex and alveolopalatal fricatives, whereas a mean value for both is given in table 3.7. The alveolopalatal fricatives have no F2 value in this table, as they do not have a recognizable peak in this frequency range. Dogil did not employ the retroflex symbol for the sounds in question, but the traditionally used palato-alveolar [ʃ] instead.

four coronal fricatives, namely a laminal alveolar [s̻], an apical post-alveolar [s̠], a laminal palato-alveolar [ʃ], and a subapical palatal [ʂ]. According to the articulatory criteria developed in chapter 2, both the subapical palatal and the apical post-alveolar fricative can be classified as retroflex. In the present section, it has to be tested whether both also comply with the acoustic criteria for retroflexion.

Shalev, Ladefoged & Bhaskararao (1993) looked at the acoustic characteristics of the four coronal fricatives [s̻, s̠, ʃ, ʂ] in Toda. Table 3.9 gives their measurements of the mean frequencies for the first peaks of the four sounds, subdivided according to context. No recordings were made for the palato-alveolar fricative in front vowel context, indicated by the dash in the corresponding cell.

Table 3.9 Mean frequency values (in Hz) of first peaks of Toda fricatives (based on Shalev, Ladefoged & Bhaskararao 1993: 114f.)

	s̻	s̠	ʃ	ʂ
oː_	2883	2192	1725	1433
æː_ / e_	2967	1742	–	1150

Compared to the subapical retroflex fricative (fourth column), the apical post-alveolar (second column) has a higher first peak (676 Hz on average), but still a much lower one than the laminal alveolar fricative in the first column (on average 958 Hz lower). The peak of the apical post-alveolar is also well above that of the palato-alveolar in the back vowel context (third column). This is no counterevidence for a retroflex nature of this segment, but indicates only that the sublingual cavity of the palato-alveolar is bigger than that of the apical post-alveolar retroflex.

Shalev et al. (1993: 114f.) also provide information on the most prominent peak in the four coronal fricatives of Toda. The mean values for these data are given in table 3.9, again split according to context. The dental fricative [s̻] is not included, as no information on its most prominent peak was given for more than half of the speakers (due to the fact that this sound usually does not have a most prominent peak in the spectrum). Again no data were available for the laminal palato-alveolar in front vowel context.

Table 3.10 Mean values (in Hz) for the most prominent peak of Toda fricatives (based on Shalev et al. 1993: 114f.)

	s̠	ʃ	ʂ
oː_	2320 – 3400	2350 – 3267	1716 – 2707
æː_ / e_	3100 – 4350	–	2269 – 3730

The subapical retroflex (third column) has the lowest peak in both contexts, in accordance with the observation made above that retroflex sounds have the lowest spectral peaks of all coronals. The peak values for the apical and the laminal palato-alveolar fricative are very close together, both slightly higher than those of [ʂ]. We noted earlier that the actual starting frequency of the friction noise and the first peak are not always the lowest for the retroflex (recall Lindblad's 1980 data), and that laminal palato-alveolar and retroflex can have very similar values in this respect. More precise statements on the retroflex status of the Toda apical post-alveolar can be given by looking at its spectral shape. Shalev et al. give only two sample spectra for each of the four fricatives of Toda (p. 112ff.). From these spectra it is obvious that the apical and subapical sounds share a downward sloping spectral shape, and a narrow range of peaks, without any prominent peaks in high frequencies (flat spectra). This is in accordance with the spectral characteristics of retroflexes as described in 3.3.2. Hence the acoustic data confirm the assumption made in chapter 2 that Toda has two retroflex fricatives.

3.3.3 Further acoustic cues

It has been pointed out in 3.3.1 above that formant transitions (and also spectral information) are not sufficient to differentiate all coronals from each other, in particular the laminal dentals and apical alveolars need additional cues to be distinguished. This section presents briefly possible additional cues, but does not develop them in detail, since they are not as relevant as formant frequencies and spectral shape for the perception of retroflexes and the description of their phonological behaviour.

In the following, the duration of segments and the voice onset time (VOT) will be treated as acoustic cues that enable the listener to recognize the places of articulation. Further examples of cues that are not discussed here include the duration of the transitions and of the burst, see for instance the measurements by McGregor (1990) on stop bursts in Gooniyandi, and the location of the burst noise, cf. Stevens & Blumstein (1975), among others.

Anderson & Maddieson (1994) state in their study on Tiwi coronal stops that the closure duration of retroflex segments is the shortest of all coronals. This remains unsupported by Dart & Nihalani's (1999: 137) measurements of coronal stop geminates in Malayalam, given in table 3.11.

Table 3.11 Duration of coronal geminates in Malayalam (mean values across nine speakers) in ms (Dart & Nihalani 1999: 137).

t̪̻t̪̻	tt	ʈʈ	t̠t̠
165	210	250	230

As can be seen from this table, the retroflex closure is the longest of all coronals. But as Dart & Nihalani (p. 137) point out, the test words used for these recordings had different vowel lengths: the dentals and half of the alveolar test words contained a long vowel, whereas the remainder contained short ones. This might have had an effect on the closure duration, as exactly these tokens had shortest closure durations.[12]

[12] Notice the cross-linguistic tendency to shorten consonants after long vowels and lengthen consonants after short vowels.

McDonough & Johnson (1997) measured the closure duration of Tamil liquids. In their study, the retroflex lateral [ɭ] had an average value of 47 ms. Compared to 71 ms for the alveolar lateral [l], the retroflex closure duration seems rather short. The values for retroflex and alveolar rhotics from the same study do not form a homogeneous pattern, either. The retroflex flap [ɽ] is 50 ms long, the retroflex approximant [ɻ] 65 ms, and the alveolar tap [ɾ] 17 ms, but this difference is most probably due to a difference in manner of articulation rather than in place.

Thus there seems to be some indication that a retroflex closure is shorter than that of other coronals, but further studies have to be conducted to confirm this hypothesis.

VOT is another cue that can be used to distinguish the four coronal places of articulation. Table 3.12 gives the mean VOT of coronal geminates from Dart & Nihalani's (1999: 137) study on Malayalam.[13]

Table 3.12 Mean VOT (in ms.) of coronal geminates in Malayalam (Dart & Nihalani 1999: 137).

t̪t̪	tt	ʈʈ	t̠t̠
20	25	15	55

In this study, the retroflexes have the shortest VOT of 15 ms., the laminal post-alveolars by far the longest, and dental and alveolar VOT are fairly close together. Shalev et al. (1993) confirm the clear cue of short VOT for retroflexion. In their study of Toda the retroflex stops have a significantly shorter VOT than any of the other stops.

3.4 Vowel dependency of cues

The description of the formant transitions in 3.3.1 indicated already that acoustic cues are to some degree dependent on context. Stevens & Blumstein (1975: 219) describe that the second formant in coronals depends very much on the vowel context. They observe a general tendency for back and low vowels to cause a lowering of the second formant, whereas front vowels keep F2 constant (around 1800 Hz), as the tongue front stays close to the place of the consonant constriction. The adjacent vowel also influences the size of the front cavity, which has a systematic effect on the adjacent consonants. Sundberg & Lindbloom (1990: 1315) point out that this cavity tends to be larger for consonants adjacent to /u/, intermediate for those adjacent to /a/, and smallest for /i/. Sussman, Hoemeke & Ahmed (1993) found that variation according to vowel context is to some degree language-dependent, a factor neglected in the discussion below.

[13] No study on the VOT of non-geminate retroflexes could be found. The gemination, however, is expected to prolong all segments similarly, thus the relations between the durations of the coronals can be taken as representative for both geminates and non-geminates.

Let us look at studies that investigated the vowel dependency of retroflexes in particular. Ohala & Ohala (2001) measured the vowel-consonant (henceforth: VC) transitions of the Hindi consonants [p, t, ʈ, tʃ, k] after the vowels [i, a, u]. They found that in all three contexts, the third formant of the retroflex is slightly falling into the consonant (the low F3 characteristic for retroflexion). Differences can be observed in the VC-transitions of the second formant. F2 adjacent to /i/ stays almost the same (at around 2200 Hz), adjacent to /a/ and /u/ it rises into the retroflex (with different degrees). These observations support the tendencies described above that a front vowel context does not change the coronal F2, whereas low and back vowels cause a lowering in F2. It is interesting to observe that all three coronals [t, ʈ, tʃ] in Ohala & Ohala's study show the same F2 transitions, but differ in the transitions of the third formant. The differences in F3 are consistent across all vowel-contexts. Furthermore, this supports the observation made above that only the lowered F3 is a stable and reliable criterion for retroflex articulation, and F2 is shared with all other coronals.

In the same study, Ohala & Ohala also conducted a perception test to see in how far the vowel context influences perception of place of articulation. The results for this test are presented in table 3.13 – 3.15, subdivided according to vowel context.

Table 3.13 Confusion matrix (in percent) for Hindi stops after the vowel /a/ (Ohala & Ohala 2001: 275).

response → stimulus↓	p	t̪	ʈ	t̠ʃ	k
p	93.7	4.8	1.6	0.0	0.0
t̪	0.0	90.5	9.5	0.0	0.0
ʈ	0.0	0.0	95.2	4.8	0.0
t̠ʃ	0.0	0.0	0.0	95.2	4.8
k	0.0	0.0	0.0	0.0	95.2

In the /a/ context, the listeners generally performed well, with a slight difference between dental and retroflex recognition, as [t̪] was miscategorized as [ʈ] in 9.5 percent of the cases. Furthermore, the retroflex was misperceived as palato-alveolar affricate in 4.8 percent of the cases. These miscategorizations might be due to missing consonant-vowel transitions, as the consonant was word-final in the test words. The results for the /u/ context are given in table 3.14 on the next page.

In this table, only one point is of interest for the class of retroflexes. The labial plosive is perceived as retroflex in 9.5 percent of the cases, though no indication for a similarity between these two sounds in /u/ context was given in the acoustic analysis of the vowel transitions.

Table 3.14 Confusion matrix (in percent) for Hindi stops after /u/ (Ohala & Ohala 2001: 275).

response → stimulus↓	p	t̪	ʈ	t̠ʃ	k
p	84.1	6.3	9.5	0.0	0.0
t̪	31.7	65.1	3.2	0.0	0.0
ʈ	0.0	0.0	95.2	4.8	0.0
t̠ʃ	0.0	0.0	0.0	95.2	4.8
k	1.6	0.0	1.6	0.0	92.1

The results for the /i/ context are represented in table 3.15. They show an asymmetry in the categorization: whereas the retroflex was never misclassified as dental, the dental was misclassified as retroflex in 23.8 percent of the cases.

Table 3.15 Confusion matrix (in percent) for Hindi stops after /i/ (Ohala & Ohala 2001: 275).

response → stimulus↓	p	t̪	ʈ	t̠ʃ	k
p	95.2	4.8	0.0	0.0	0.0
t̪	4.8	71.4	23.8	0.0	0.0
ʈ	1.6	0.0	92.1	4.8	1.6
t̠ʃ	0.0	1.6	17.5	76.2	4.8
k	0.0	0.0	0.0	0.0	95.2

Furthermore, the palato-alveolar affricate was classified as retroflex in 17.5 percent of the cases, and the retroflex as palato-alveolar in 4.8 percent. This confusion might be explained by the similarity in formant transitions for both segments in /i/ context, as both show a near convergence of F2 and F3, as Ohala & Ohala indicate. It can be concluded from the results for the /i/ context, that an adjacent front vowel with its high F2 value yields more confusion between the coronal segments than any other vowel context. This might be due to the fact that the closeness of F2 to F3 might mask the actual transition of the F3. Interestingly, the similarity between velar and retroflex (and partly labial and retroflex) in the /i/ context did not have any influence on the perception test. The distinctions in the open and back vowel were generally better, as in this context the coronals have slightly diverging F2 values, which helped identifying the place of articulation.

McDonough & Johnson's (1997) and Narayanan & Kaun's (1999) experiments on Tamil liquids support the findings for the stops, though manner-specific differences could be observed: the retroflex lateral generally showed a lower F2 value and a higher F3 value than the retroflex rhotic. The differences in formant transitions depending on vowel context can also be observed in fricative spectra. Lindblad (1980) compared the spectra of the Swedish fricatives in different vowel contexts. Though they differed quite extensively in the shape of the spectra even for the same place of articulation, the retroflex spectra consistently show the lowest cut-off frequency of all fricatives (across different speakers).

3.5 Symmetrical spread of retroflex cues

The acoustic signal of a retroflex segment shows some asymmetry between the transitions into and transitions out of the segment, as noted e.g. by Dave (1977) and Steriade (1995, 2001a). Whereas the transitions from a vowel into a consonant (henceforth: VC transitions) for retroflexes show some distinct lowering of the third formant (and mid to high F2 according to the vowel context), the CV transitions are far less extensive, and are closer to those from other coronals, especially apicals. This acoustic similarity was attested in several phonetic studies. For example, Spajić et al. (1996: 17) found that the retroflex trill in Toda "starts off retroflexed and ends up in a position more like that of the alveolar rhotic". Their comparison of the formant frequencies of the retroflex at onset, middle, and offset (in postvocalic context) in the study on Tamil shows this difference: the onset frequency is on average (across five vowel contexts) 340 Hz lower than the offset frequency (ibid.). Similar observations were made by Dave (1977) for Gujarati and Anderson & Maddieson (1994) for Tiwi.

The class of retroflexes differ very much from other consonants in this respect, which usually show stronger CV cues than VC ones, as attested by Ohala (1990), Sussman et al. (1997), and Warner (1999), among others.

The similarity in CV cues for retroflexes and apicals can be explained by examining the articulatory characteristics of the retroflex. A retroflex articulation involves a movement of the tongue tip towards the post-alveolar place of articulation before the actual stop closure. This movement results in a sizeable lowering of the VC transitions. During the constriction phase, the tongue tip is moved to a less displaced position (the so-called flapping out gesture as described in chapter 2), so that by the time of the constriction release it is in a position close to that of an apical alveolar, at least for stops and flaps. This results in CV transitions similar to that of an apical alveolar (Ladefoged and Maddieson 1996: 28). Krull et al. (1995) studied Tamil, Hindi, and Swedish retroflex stops and found that in all three languages this class showed a more posterior articulation at the beginning of the closure than at the release.

The asymmetry of cues can explain why retroflex neutralization occurs often in word-initial position and post-consonantally, but less often in post- or intervocalic position, as Steriade (1995, 1998, 2001) argues. Nevertheless, some work shows that the CV cues of retroflexes are strong enough to distinguish them from apical alveolars in non-VC prominent positions, see e.g. McGregor (1990: 70f.) on Gooniyandi, Platt (1972: 7) on Gugada, and Blake (1979: 190) on Pitta-Pitta. Evidence for this strength can be gleaned from the fact that there are several languages like Hindi that distinguish between retroflex and non-retroflex apical phonemes in word-initial position, where VC cues are not available to the listener. A list of such languages from

Australian and some examples illustrating this phenomenon are given in section 4.5 on neutralization.

Whether VC cues are really more dominant than CV cues can be tested in perception experiments. Öhman (1966) tested all Swedish stops (including dentals and retroflexes) in the context of the vowel /a/. The listeners had to judge four types of signals; the whole, the VC part, the CV part, and the release only. The CV signals for retroflexes were poorly perceived. Öhman speculates that this is due to "the non-Swedish syllable structure of these utterances" (1966: 988). Krull (1990) constructed a test similar to Öhman's: she tested Swedish voiced stops only, with the same four types of signals. Her results are 11.8 percent misperception of retroflex VC signals as dental, whereas only 7.3 percent of the retroflex CV signals were miscategorized as dentals. Ahmed & Agrawal (1969) tested the perception of CVC words with all Hindi consonants. The words were presented to Hindi listeners as CV and VC signals. Their results show that CV cues are more reliable for retroflexes, as they yielded only one percent of misclassification, opposed to 7.5 percent of retroflex misclassification in VC condition. Summing up these perception studies, there is a large inconsistency in the results. Öhman (1966) shows that retroflex VC cues yield fewer miscategorizations than retroflex CV cues, indicating that VC cues are stronger. Krull (1990) and Ahmed & Agrawal (1969), on the other hand, found that CV cues of retroflexes fair better in a classification task. The outcome of these experiments cannot be attributed to language-specific differences, as the two opposing results for the tests on Swedish (Öhman 1966; Krull 1990) show.

Hamann (2003) conducted a so-called cross-splicing perception experiment (as used by Repp 1978 and Ohala 1990) with Norwegian dental and retroflex stops and nasals. In this test, dental and retroflex signals in the same vowel contexts were cut in the stop phase of the plosive and in the middle of the nasal and re-combined in such a way that the resulting signal had VC cues of one place of articulation and CV cues[14] of the other. Six Norwegian and six German native listeners were then asked to categorize these signals (four repetitions of each stimulus item in intervocalic [a] and [i] context) as either one segment or the other, or neither.[15,16] The results of this study for the voiceless plosives are presented in tables 3.16 and 3.17 on the next page. The data is split into the /a/ and /i/ contexts, respectively, as there is considerable difference between both. Answers by the Norwegian subjects are given on the left, those by the German subjects on the right.

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[14] CV cues' of the plosives here and in the following is meant to include the stop burst, which has additional information on the place of articulation.

[15] My experiment also included gated signals, i.e. stops without burst and nasals without sufficient CV cues. As this condition is not relevant for the present argument, the data are not included.

[16] The original test was planned to include fricatives, but the cross-spliced fricative stimuli yielded perceptually non-homogeneous, disturbing signals that could not be classified as either dental or retroflex.

Table 3.16 Confusion matrix (in percent) for stops in the /a/ context (Hamann 2003).

response → stimulus ↓	Norwegian subjects			German subjects		
	t	ʈ	∅	t	ʈ	∅
tʈ	90	10	0	71.4	28.6	0
ʈt	0	100	0	28.6	71.4	0

The results for the stops in the /a/ context show that VC cues dominate the classification for both German and Norwegian native speakers. For the Norwegians, the retroflex CV cues affected the categorization slightly because 10 percent of the [tʈ] signals were classified as retroflex, whereas the denti-alveolar CV did not have any influence, as all [ʈt] signals were categorized as retroflex. This is in accordance with Ohala & Ohala's (2001) findings. The German subjects were affected by the presence of the CV cues in both denti-alveolar and retroflex cases, as 28.6 percent of the signals were classified according to these cues.

The responses to stop signals in an /i/ context are presented in table 3.17.

Table 3.17 Confusion matrix (in percent) for stops in the /i/ context (Hamann 2003).

response → stimulus ↓	Norwegian subjects			German subjects		
	t	ʈ	∅	t	ʈ	∅
tʈ	73.3	13.3	13.3	47.6	52.4	0
ʈt	0	80	20	28.6	61.4	10

The Norwegian listeners again paid more attention to the VC cues of the retroflex than to the VC cues of the dentals. This time, the dental CV cues led to some confusion and a choice of 'neither' in 20 percent of the cases. German listeners were strongly influenced by the retroflex CV cues, which determined their choice of category in 52.4 percent of the cases. The influence of the dental CV cues did not change compared to the /a/ context, but in 10 percent of the answers to these cues the listeners did not classify the signals. The /i/ vowel context thus resulted in quite different answers compared to the /a/ context, particularly the retroflex and denti-alveolar VC cues are less distinct in this context (for an explanation, recall the influence of the vowel context on the coronal cues described in 3.4). The responses to nasal signals are presented in the following two tables. The signals in the /a/ context, given in table 3.18, show a clear dominance of retroflex VC cues for both subject groups. The denti-alveolar VC cues are overridden by the CV cues of the retroflex in 46 percent of the cases for the Norwegian listeners, and in 38.1 percent of the cases for the German listeners.

Table 3.18 Confusion matrix (in percent) for nasals in the /a/ context (Hamann 2003).

response → stimulus ↓	Norwegian subjects			German subjects		
	n	ɳ	∅	n	ɳ	∅
nɳ	54	46	0	57.1	38.1	4.8
ɳn	0	100	0	14.3	85.7	0

The general result for nasals in an /a/ context differs from that for stops in the same context (see table 3.16), in as far as the VC cues are less dominant. This is probably due to the strong internal cues of nasals, which give contradictory information of two places of articulation to the listener. For the nasals in /i/ context, see table 3.19, the VC cues dominated clearly.

Table 3.19 Confusion matrix (in percent) for nasals in the /i/ context (Hamann 2003).

response →	Norwegian subjects			German subjects		
stimulus ↓	n	ɳ	∅	n	ɳ	∅
nɳ	66.7	13.3	0	95.2	4.8	0
ɳn	0	100	0	4.8	80.9	14.3

The results of Hamann's test show that retroflex VC cues determine the classification of the sound much more often than retroflex CV cues. But one has to keep in mind that the retroflex cues always had to compete with dental cues. Thus, the results cannot be interpreted as retroflex VC cues being stronger than retroflex CV cues. Rather, retroflex VC transitions dominated denti-alveolar CV transitions. In the reverse case of signals with denti-alveolar VC and retroflex CV, the denti-alveolar VC cues were dominated by retroflex CV cues in 25.8 percent of the cases (compared to 9.5 percent of dominating CV cues of denti-alveolars). This indicates that both retroflex transitions are stronger than the corresponding dental ones.[17] Furthermore, the vowel context had some impact on the results, as it added some indecisiveness (the choice of the option 'neither' rose from 0.6 percent in /a/ context to 7.2 percent in /i/ context). The nasals were influenced by the vowel context to a smaller degree because of their strong internal cues.

Thus in contrast to the previous tests, the cross-splicing experiment by Hamann (2003) showed that for both apico-dentals and retroflexes the VC cues dominate the perception, despite the fact that the CV cues of retroflexes are sometimes strong enough to override dental VC cues. This implies that though there is an asymmetry in the signal of retroflex segments in the shape of more extensive VC transitions than CV ones, the CV cues of retroflexion are still strong enough to give the listener information on the place of the articulation. Hence, the asymmetrical spread is an interesting phonetic effect, but has no direct impact on the occurrence of retroflex segments. Furthermore, it should be noted that retroflexes are not the only place of articulation that display this kind of asymmetrical behaviour with respect to VC cues. According to Hamilton (1996: 47), laminal palato-alveolars have more robust cues in VC transitions than in CV transitions, which often condition a diphthongization of the preceding vowel, as in Djabugay (Patz 1991: 254).

[17] For a discussion of the language-specific differences in categorization, see Hamann (2003).

3.6 Retroflexion as a weak cue and its possible enhancement

Some phoneticians and phonologists, such as Stevens et al. (1986) and Stevens & Keyser (1989), make a distinction between robust (basic) and weak (redundant) acoustic features, recall the discussion in section 1.2. Robust features are defined as features that are manifested in a very short time (within a few miliseconds), whereas so-called weak features require much more time to be detected. According to Stevens et al. and Ohala (1993: 89), [coronal] is a robust feature, but its dependent [retroflex], which is said to have a rather slow acoustic modulation and to be detected later by the auditory system, is a weak cue. Ohala (1985) claims that languages with small inventories utilize segments which consist of robust features, and only languages with larger inventories use the less salient features. Ohala therefore argues for the weakness of retroflex cues as an explanation for their restricted occurrence: "if a language has one apical stop, it is generally not retroflex" (p. 225).

This section argues against the claim that retroflexion is a weak cue and that the reason for the scarcity of inventory segments with a retroflex as the only coronal is to be found in the acoustic cues for retroflexion. It is assumed instead that the articulatory complexity of the retroflex gesture accounts for its scarcity cross-linguistically. Furthermore, this section deals with another concept associated with acoustic cues, namely that of 'cue enhancement', as described by Stevens et al. (1986). It will be shown that the notion of cue enhancement is problematic for several reasons.

Let us look at the supposed weakness of the retroflex cues first. It was illustrated in section 3.3.1 that the main acoustic cue for retroflexes, namely the lowering of F3, by no means takes more time, nor is it harder to detect, than that of any other coronal place of articulation. On the contrary, the trajectories of F3 for a retroflex are very distinct, especially in VC transitions. This means that already at the beginning of the acoustic signal the cues are strong enough for a correct identification of retroflexion. Support for this claim can be derived from Hamann's (2003) cross-splicing experiment, where the retroflex place of articulation could be detected more reliably than the dental place, only on the basis of a part of the cues (VC or CV). The phonetic grounding of a supposed 'weakness' of retroflex cues is therefore missing, unless one argues that all coronal sub-articulations, i.e. retroflex, apical alveolar, laminal dental, and palato-alveolar, are detected only after a general cue for coronality is perceived. This, however, raises the question of whether the auditory system really detects some superset such as 'coronal' prior to the subset 'retroflex' or 'palato-alveolar'. If it does, what are the cues triggering the coronal place of articulation in general? We saw in section 3.3 that a high F2 seems to be the unifying acoustic feature for coronals. But this cue is shared with other places of articulation, e.g. with velars or labials in front vowel context. In addition, one would expect subjects in perception experiments to miscategorize within the coronal class, if 'coronal' were to be detected prior to the exact coronal place of articulation. However, perception experiments do not attest such a behaviour, recall Ohala & Ohala's (2001) results in section 3.4 above.

Ohala's argument that languages tend to utilize strong features in small inventories and weak ones only redundantly or in larger inventories might be understood as evidence for the weakness of retroflex cues. But as was illustrated in section 1.1, the restricted occurrence of retroflexes is rather due to its articulatory complexity then to its perceptual weakness. Thus, there is no need and no evidence to postulate weak cues for retroflexion in order to explain their cross-linguistic scarcity.

Moving on to the second point, cue enhancement, Stevens et al. (1986) claim that languages can choose among a variety of articulatory gestures or secondary articulations to enhance the perception of retroflexion. Both rounding (or labialization) and velarization are assumed to serve this purpose by Stevens et al. and Flemming (2002). As was argued extensively in chapter 2, retroflexion is assumed to always co-occur with retraction, i.e. velarization, in the present dissertation. It is therefore difficult to decide in how far velarization serves to enhance the retroflex cues. The secondary articulation of rounding, on the other hand, is not a concomitant feature of retroflexion. Rounding enlarges the front cavity, resulting in a general lowering of the frequencies of all formants (recall the discussion in 3.2.3 on the sublingual cavity). Retroflexes are characterized by a mid to low F2, lowering of F2 is thus no additional cue for detecting retroflexion and does not enhance the retroflex cues. Only the lowered F3 caused by rounding might serve this purpose.

These observations lead to the question of how a segment can be enhanced, if it has already a certain degree of the cue to be enhanced. Enhancement then seems to be only possible if the degree of the cue is not maximal. Applied to retroflexes this means that only those retroflexes might undergo enhancement which do not show a strong lowering of their F3 already. This is the case for non-posterior retroflexes and retroflexes in a front vowel context. Both can undergo a further lowering of the F3 either by enlarging the sublingual cavity (i.e., changing into a retroflex with posteriority, which applies to the non-posterior retroflex only) or by rounding (which enlarges the front cavity and applies to both). The latter can be found for example in the Polish retroflex fricatives, which lack the criterion of posteriority and are reported to be rounded (recall the description in section 3.3.2.2).

Furthermore, it is not clear how one can distinguish which articulatory configuration is responsible for enhancing an acoustic cue, if complex tongue positions such as those for retroflex segments are assumed. If retraction is assumed to be a concomitant property of retroflexion as done in the present dissertation, both articulatory movements result in similar acoustic consequences, and it cannot be decided which gesture enhances which (see Boersma 1998: 359f. for a similar argumentation). This casts doubt on the usefulness of the notion cue enhancement, at least for the retroflex class.

3.7 Acoustic incompatibility: Retroflexion and palatalization

It has been argued in section 2.5 that the palatalization of retroflexion, which is sometimes claimed to exist for certain segments in Polish and Kashmiri, is articulatorily impossible, as the two gestures of flat, retracted tongue body and raised tongue body cannot be produced at the same time. Instead, it was argued that the secondary palatalization of a retroflex segment triggers a change from an apical post-alveolar (i.e., retroflex) to a laminal palato-alveolar (for fricatives) or post-alveolar (for other manners).

This section will show that there are also acoustic reasons why a palatalized retroflex is impossible. We saw above that retroflex segments are characterized by a low F3 and an average or high F2 value. Secondary palatalization has the acoustic property of a considerable raising of F2, and a slight raising of F3 (Brosnahan & Malmberg 1970: 67). If we apply these changes to a retroflex segment, the resulting sound would be expected to show a high F2 and an average or high F3 (in addition to further cues that indicate the manner of articulation). High F2 is a characteristic of all coronals as was shown in section 3.3.1, though retroflexes often only have a high F2 in a front vowel context (recall the discussion in section 3.4). A non-low F3, however, cannot be interpreted by the listener as retroflex anymore when the articulatory change for secondary palatalization occurs, as a low F3 is the only stable acoustic characteristic of retroflexion. Instead, the listener will perceive a sound with a high F2, i.e. a laminal coronal, since laminals have higher F2 frequencies than apicals (see 3.2.1), with a middle to high F3, which indicates a laminal palato-alveolar.[18] Thus, the secondary palatalization of retroflexion results acoustically in a non-retroflex segment, supporting the claim made in section 2.5 that articulatory demands change the retroflex into a non-retroflex segment under secondary palatalization.

Languages that have a palatalized counterpart to a retroflex, such as [ʃʲ] in Polish and Russian as the palatalized counterpart of [ʂ], show a kind of repair mechanism to maintain some similarity to the original sound: they add distinctive rounding to the palato-alveolar. As we saw in the previous section on cue enhancement, rounding has the effect of lowering the third formant. The rounded, palatalized palato-alveolar thus preserves one cue of retroflexion.

3.8 Summary

It was shown in this chapter that the four articulatory properties of retroflexes proposed in chapter 2 yield exactly those acoustic characteristics that can be observed for this class in natural languages, providing additional evidence for the proposed properties. Furthermore, retroflexes could be shown to have the common acoustic characteristics of a low F3 (which is also observable in friction noise as a lower first peak in the friction energy than is found for example in other sibilants), and a mid or high F2, the latter depending on the vowel context. The low F3 shows some variation in the degree of lowering, depending on two factors: the language in which the segment occurs and its vowel context. Languages differ in the exact place of articulation of a retroflex, and the further back the place, the lower the F3. A non-posterior

[18] Note that the laminal palato-alveolar that is argued to emerge acoustically from the secondary palatalization of a retroflex is identical to what has been argued to be the articulatory result in chapter 2.

retroflex therefore has a less lowered F3. Furthermore, retroflexes in a back vowel show a lower F3 than those in any other context.

Though retroflex cues are not symmetrically spread, and the VC cues seem to be more distinct than the CV cues, it was argued that retroflexes cannot be detected by their VC cues alone and that the CV cues play a role in distinguishing retroflexes from other places of articulation. Therefore it is assumed that low F3 holds for all retroflexes in all positions. As argued already in chapter 1, no indication could be found for the alleged weakness of retroflex perceptual cues.

Both chapters 2 and 3 make up the phonetic part of this dissertation. These chapters give an articulatory and an acoustic definition of the class of retroflexes as they are going to be used in the phonological part in chapters 4 to 6. The definitions and thus the phonetic space of this class (as depicted in figure 1.2 in chapter 1) were chosen as unrestricted as possible to include borderline cases of retroflexion. Alternative, more restricted definitions and their consequences for phonological classification will be shortly discussed in chapter 7.

4 Retroflex processes and their phonetic grounding

In this chapter, cross-linguistically very common phonological processes involving retroflex segments are discussed. These processes are: retroflexion in a rhotic context and in a back vowel context, de-retroflexion in a front vowel context (and in secondary palatalization) or retraction of the front vowel, retroflexion of velarized or labialized segments, retroflexion of vowels before retroflex segments, non-occurrence of retroflexes word-initially and post-consonantally, and (local and non-local) assimilation of non-retroflex coronals. They are represented in this order in (1), where *t* is a cover symbol for a [+anterior] coronal, and *ʈ* for a retroflex segment. *C* is any kind of consonant, *V* any kind of vowel, and *(*$_\omega$ indicates the left boundary of a prosodic category higher than the syllable (phonological word, phrase boundary). The first column gives the inputs, the second the outputs, and the third gives these processes terms that I will continue to use in this and following chapters.

(1)		*input*	*output*	*process*
	(a)	/rt/	[ʈ]	retroflexion in rhotic context
	(b)	/ut/	[uʈ]	retroflexion in back vowel context
	(c)	/iʈ/	[it] or [ɨʈ]	deretroflexion or vowel retraction
		/ʈ^j/	[t^j] or [ʈ]	deretroflexion or depalatalization
	(d)	/Vʈ/	[V^{ɻ}ʈ]	retroflexion of adjacent vowel
	(e)	/ʈ/	($_\omega$[t], C[t]	phonotactic restrictions on retroflexes
	(f)	/ʈt/	[ʈʈ]	local assimilation of retroflexes
		/ʈVt/	[ʈVʈ]	non-local assimilation of retroflexes

Bhat (1973) already described some of the processes in (1), namely the retroflexion of dentals or alveolars by a preceding /r/ (1a), by a preceding back vowel (1b), and a preceding retroflex consonant (1f). Retroflexion caused by implosion, another process elaborated by Bhat (p. 43), will not be treated here, as I want to restrict my investigations to normal egressive airflow. Two further processes of retroflexion that I found when collecting and analysing the data are not included in the descriptions below and the analysis in chapter 6: these are retroflexion via secondary velarization and via secondary rounding, see (2a) and (2b), respectively.

(2)				
	(a)	/t^ɣ/	[ʈ]	retroflexion of velarized segments
	(b)	/t^w/	[ʈ]	retroflexion of labialized segments

These processes are phonetically motivated, since retroflexion via velarization is a type of articulatory assimilation if one assumes retroflexes to be inherently retracted, and retroflexion via rounding has obvious perceptual similarities between input and output, cf. section 4.3.2.4 on the rounding of vowels before retroflexes. Nevertheless, the two processes are not included here, because of the lack of clear supporting examples. Ponapean is the only language I found that might have introduced retroflexes via velarized alveolars, though the literature (Rehg 1973, Harrison 1995) is not very explicit on this point. Retroflexion via secondary rounding seems to have been a diachronic process in Athapaskan; the affricate [ʈ^{ɽ}] in Minto-Nenana originates from a rounded segment, though the actual realization of it is a topic of unclarity. Krauss (1973) describes the respective Proto-Athapaskan segment as */k^{w}/, Tharp (1972) refers to it as */t^{w}/, and Rice as (1989) */t^{ʃw}/. I leave the clarification of these data and the collection of further examples of both processes open for future research.

Bhat (1973) found that rules of retroflexion are typically caused by a preceding non-retroflex sound or by the retroflexion spreading leftward, i.e. the expected order in the input is a non-retroflex followed by a retroflex segment. This will be shown to be a general tendency for the examples given in this chapter, but even so most of the phonological changes in (1) will be shown to occur also in reverse segmental order of input (and also output), namely the retroflexion in rhotic context (1a) and in back vowel context (1b), avoidance of front vowel context (1c), and assimilation processes (1f). Examples in the subsections below will illustrate this point. Not all of the processes have retroflex segments as outputs (as (1a), (1b), and (1f)); some of them have retroflexes as input (for instance, the process of de-retroflexion in (1c) and (1e)), others are only triggered by retroflexes (for instance, the vowel changes in (1c)).

For each change in (1), evidence from several language families is given in order to show the universal validity of the process. This universality is argued to be based on the phonetic grounding of these processes, explained by the articulatory and acoustic characteristics of retroflexion as elaborated in chapters 2 and 3, respectively. The present chapter gives no phonological account of the processes involving retroflexes. The data collected here show general, recurring patterns that will be represented in the phonological formalizations of retroflexes in general in chapter 5 and of these processes specifically in chapter 6.

The present chapter is structured as follows. Section 4.1 deals with retroflexion induced by rhotic segments (1a). In section 4.2, the retroflexion of coronals in back vowel context is discussed (1b), whereas section 4.3 deals with the opposite process, non-retroflexion in front vowel context (1c). Vowel retroflexion (1d) is the topic of section 4.4. In section 4.5, the phonotactic restrictions of retroflexes (1e) are discussed. Lastly, section 4.6 deals with local and non-local assimilations of retroflexes (1f). All of these sections are subdivided into two subsections, where the first presents the examples and the second gives the phonetic grounding of the process under discussion. Section 4.7 concludes.

Before starting with the detailed discussion, a note on the transcription is necessary. In the examples throughout the chapter, the retroflexes are represented by their respective IPA symbols, which sometimes depart from their description in the original sources. I also transferred non-retroflex segments into respective IPA symbols if the sources used other transcriptional systems.

4.1 Retroflexion in rhotic context

The first process to be discussed here is the change of an anterior coronal into a retroflex caused by a rhotic, as illustrated in (1a). This process can be found in North-Germanic languages, in Australian languages and Indo-Aryan languages. It is also diachronically attested in some of these languages, and is responsible for the introduction of retroflex phonemes into a number of languages, as illustrated below in 4.1.1. Section 4.1.2 will provide a possible explanation based on the acoustic characteristics of the segments involved in this process.

4.1.1 Examples

Before examples of this process are given, one problem in its description has to be pointed out. Due to the lack of appropriate graphemes for retroflex sounds in Latin-based writing systems, different methods for representing these sounds are employed in languages with retroflex phonemes. One of them is to write a sequence of *r* plus *t, d, s, n, l,* or *r*. This is often found in the literature on Australian languages, see for example McKay (2000) on Ndjébbana.[1] Such a transcription convention should not be confused with an underlying sequence of two phonemes, namely a rhotic and an alveolar or dental, which can be realized with one phoneme via a phonological contraction rule, as demonstrated below. The difference of these two representations is of particular importance for the North-Germanic languages Swedish and Norwegian, which are assumed to have a retroflex phoneme and a sandhi-process of retroflexion, both represented graphemically in the same way.

In Norwegian,[2] the so-called 'retroflex rule' merges clusters of apical alveolar /r/[3] or retroflex flap /ɽ/ plus all laminal dentals /t, d, s, n, l/ into corresponding retroflexes across morpheme and word boundaries. Examples from Kristoffersen (2000: 96f.) are given in (3) (in Kristoffersen's transcription).

(3)		*input*	*output of RR*		*gloss*
	Inflection	/sʉr-t/	[sʉːʈ]	*surt*	'sour' AGR
		/bar-n/	[bɑːɳ]	*baren*	'bar' DEF-SG
	Derivation	/ʋor-li/	[ʋoː.ɭi]	*vårlig*	'spring-like'
	Clitics	/brur-s/	[bɾuːʂ]	*brors*	'brother' POSS
		/bær-n/	[bæːɳ]	*bær han*	'carry him!'
	Compounds	/ʋor-tejn/	[ʋoː.ʈæjn]	*vårtegn*	'spring sign'
		/ʋor-dag/	[ʋoː.ɖɑːg]	*vårdag*	'spring day'

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1 Other systems employed to represent retroflexes in the literature on Australian languages are the usual grapheme for coronals (d, n, l, r) with a subscript dot or an underlining. A further option is to transcribe retroflexes with capital coronals, as used for example in the Dravidian language Kannada (Schiffman 1983, Sridhar 1990).

2 The term "Norwegian" is used here and below to cover the variety that is defined as urban East Norwegian speech, a notion explicated for example by Vanvik (1972, 1973), Endresen (1974), and Kristoffersen (2000).

3 The underlying apical alveolar /r/ is realized as a tap [ɾ] in Norwegian (Kristoffersen 2000: 24).

The geographical domain of the retroflex rule does not hold for the whole of Norway, but extends only over the eastern part of South Norway all the way up north to the Russian border (Kristoffersen 2000: 88). This area coincides with that of the spread of the apical rhotic, which led some scholars, such as Torp (2001), to propose that retroflexion can only occur with coronal /r/, whereas the uvular /ʀ/, which is used in the remaining part of the country, blocks retroflexion.

Swedish has a similar rule of retroflexion, which is sometimes called post-alveolarization or supradentalization (Eliasson 1986: 278). Examples of this process are given in (4) (in Eliasson's transcription).

(4)	*input*	*output*		*gloss*
Inflection	/før–t/	[fœ̜ːʈ]	*fört*	'brought' SUP
	/før–s/	[fœ̜ːʂ]	*förs*	'is brought' PASS
Derivation	/før–tal/	[fœ̜ˈʈɑːl]	*förtal*	'slander'
	/før–sorj/	[fœ̜ˈʂɔrj]	*försorg*	'taking care'
Compounds	/før–tɯr/	[ˈfœ̜ːˌʈɯːr]	*förtur*	'priority'
	/før–sal/	[ˈfœ̜ːˌʂɑːl]	*försal*	'entrance hall'
Across words	/før tɯnː/	[fœ̜ˈʈɵnː]	*för tunn*	'too thin'
	/før sen/	[fœ̜ˈʂeːn]	*för sen*	'too late'

According to Eliasson (1986: 282), the sandhi rule of retroflexion in Swedish is sensitive to the type of boundary between the /r/ and the dental. The higher up in the prosodic hierarchy the two categories are, the less likely retroflexion occurs across their boundary.

Both Norwegian and Swedish also have retroflexes which cannot be the result of the merger in (4) because no morpheme boundary occurs between /r/ and the dental, e.g. *kart/karta* [kʰaʈ(a)][4] 'map', or *kors* [kʰɔʂ] 'cross'. In most cases these retroflexes derive historically from the same retroflexion rule as those described above. Due to this common origin, Endresen (1974) among others proposes that there are no underlying retroflex phonemes and that all retroflexes are derived via the same rule. Since the rule is not triggered by a morpheme boundary in examples like /kʰɔrs/, Endresen assumes that it applies across the board. This assumption is problematic for the following reasons. First of all, not all word-internal retroflexes in Norwegian can be derived from rhotic plus dentals: the retroflex fricative in words like *skje* [ʂeː] 'spoon', and the retroflex flap in words like *sol* [suːɽ] 'sun' (Kristoffersen 2000: 23 and 24, respectively) have a different historical origin. To account for these forms with a context-free retroflexion rule, one has to assume the underlying forms /rseː/ and /suːrr/, respectively, which would violate the sonority sequency generalization.

Furthermore, the graphemic sequence *rd* is often not retroflexed, and some words exist that show variation between retroflexion and non-retroflexion (Kristoffersen 2000: 89). *Bård*, for instance, a male Christian name, can be pronounced as [boːɖ] or [boːɾ], whereas other words can only be pronounced with the retroflex voiced stop, e.g. [fɔ.ˈɖiː] *fordi* 'because' or [gɑ.ˈɖiːn] *gardin* 'curtain'.

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4 The form with the /a/ is the Swedish, that without /a/ is the Norwegian.

In addition, the retroflexion of *rd* is stress-dependent: after stressed vowels one finds almost only [ɾd], after unstressed vowel only [ɖ], see for example the alternations: *garde* 'guard' [ˈgɑɾ.də] and derived *gardist* 'guardsman' [gɑ.ˈɖist], where the stress is moved to the suffix. /rd/ after long vowels can be pronounced as so-called 'thick l' [ɽ], e.g. *ard* 'plough' [ɑːɽ] (Popperwell 1963: 83).

For these reasons, the present study follows Kristoffersen (2000) among others in assuming an underlying retroflex phoneme and a sandhi rule of retroflexion that applies across morpheme and word boundaries in both languages.

Retroflexion does not necessarily have to be induced by an *apical* rhotic, as the following description of a Swedish dialect suggests. Svantesson (2001) describes the phoneme inventory of his own southern Standard Swedish idiolect. Instead of the apical trill or fricative, this variety has a uvular fricative [ʁ], like all Southern Swedish dialects. Svantesson's idiolect shows deletion of the rhotic when occurring in coda position as the first member of a cluster. A following dental consonant is retracted, and becomes 'alveolar' in Svantesson's terms (p. 157), which he represents as /t̲, d̲, s̲, n̲, l̲/. His study unfortunately does not contain any articulatory data to infer the exact articulation of these retracted segments, and no other study on the articulation of Southern Swedish dentals and alveolars could be found to serve this purpose. However, the description of these segments allows the interpretation that they are non-posterior retroflexes (see the definition in section 2.3.5): the segments in question cause preceding vowels to lower and rhotacize, and therefore behave phonologically like retroflexes, cf. sections 4.3.2.2 and 4.4 below. The retraction of dentals in Svantesson's data suggests that the retraction of coronals in r-context is not caused by coronal rhotics only, but can be triggered by uvular rhotics as well. It remains open for future articulatory studies to determine whether the resulting segments are indeed retroflexes (i.e., apical post-alveolars). If that were the case, it would show that retroflexion can be induced by non-coronal rhotics, too. Furthermore, it would provide evidence against claims that retroflexion does not occur in regions with a uvular rhotic, as proposed by Torp (2001) and others.

Australian languages are another language-family that shows retroflexion in a rhotic context. Bhat (1973: 35) points out that in these languages the morphophonemic sequences of /r/ + /t/ are generally realized as retroflexes. An example of this is Ndjébbana (McKay 2000: 175), spoken in Central Anrhem Land. Ndjébbana has a contraction process for the 'realis prefix' *rra* [ra] followed by a root with an initial apical alveolar /n/: this may show vowel deletion to /rn/ and subsequent realization as a retroflex nasal [ɳ], see the example in (5).

(5)	ba-**ra**-**n**maramaɭo-ŋa	(> ba-**rn**maramaɭo-ŋa)	>	ba**ɳ**maramaɭoŋa
	3rd PS-AUGS-RE-swim-REM			'they swam'

Another example of morphophonemic retroflexion is Watjarri (Douglas 1981), spoken in South-Western Australia, which has the ergative and locative affixes *–tu* and *–ta*, respectively, which change their initial apical alveolar /t/ into a retroflex when the preceding stem ends in an alveolar /r/. An example for this process is the sequence /maju maɳku**r**/ 'the three children', which changes into [maju maɳku**ʈ**a] 'on the three children' when locative *-ta* is added (Douglas 1981: 208). Note that the rhotic does not have to be retroflex.

Diachronically, old Indo-Aryan (i.e. Sanskrit) developed a retroflex fricative partly by a rhotic /r/ which changed a following /s/ into a retroflex. For discussion see section 4.3.4 on the *ruki* rule below. Another sub-branch of the Indo-Iranian language family, namely Iranian, shows a similar retroflexion process. Several Modern Iranian languages developed retroflexes via rhotics.[5] In the Iranian language Yidgha, spoken in Pakistan, the retroflex [ɳ] developed from the sequence /rn/, and the phoneme [ʂ] from /rʃ/ (Bhat 1973: 34, Skjærvø 1989c: 411). Interestingly, /rt/ developed into [ɽ], not into a retroflex stop.[6] Yidgha also introduced the phoneme [ʂ] via the sequences /str/ and /sr/ (Skjærvø 1989c: 413), an instance of regressive influence of a rhotic. This development is rather common in Modern East Iranian languages. Pashto, for example, shows exactly the same process causing the retroflex fricative to become a phoneme, as corresponding words in the predecessing language Avestan indicate: Pashto [ʂa] 'good' and [ʂna] 'hip bone' correspond to Avestan [srao] and [sraoni], respectively (Morgenstierne 1927). Further examples for such a development can be found in Wakhī, Sanglīčī, and Iškašmī (Payne 1989), and in Munǰī (Skjærvø 1989a). The Indo-Aryan language Sindhi developed retroflexes from dentals preceding *r*, but here the rhotic remained: Old-Indo-Aryan *traya-* 'three' or *draka* 'grape' changed to Sindhi [ʈreː] and [ɖraːkʰa] (Masica 1991: 210).

A rhotic causing a segment to the right to change into a retroflex as in the Iranian Pashto and the Indo-Aryan Sindhi is a process that occurs cross-linguistically less often than a rhotic causing a change of the segment to its left (as in Norwegian, Swedish, Ndjébbana, and Watjarri). A further instance for this latter assimilatory direction is Cham, spoken in Vietnam (Bhat 1973: 36), in which retroflexes were diachronically introduced via an anterior coronal plus following /r/. The changes that occurred here were: tr > ʈ, tr' > ʈ', and sr > ʂ. A similar process can be observed in some Southern dialects of the Dravidian language Tamil, which realize literary Tamil /nr/ as [ɳɖ], e.g. *anru* 'that day' is [aɳɖu] in Ceylon Tamil, or /muːnru/ 'three' [muːɳɖu] (Zvelebil 1970: 173).

In some central African languages, which sometimes have retroflexion of the voiced coronal stop, this retroflexion is triggered partly by a following /r/ as for example in the Nilo-Saharan Lugbara, where the stops in *tr* and *dr* can be retroflexed without deletion of the rhotic (Bhat 1973: 40).

The diachronic development of a retroflex from a following rhotic can be observed in the Sino-Tibetan language Tibetan and its closely related neighbouring languages. Bhat (1973: 34) gives examples of this development, which took place in syllable-initial consonant clusters, see (6).

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5 In some of the Iranian languages, the introduction of a retroflex via a sequence of rhotic plus dental was accompanied by a change in manner. Sanglīčī, for example, spoken in Tadžikistan, introduced a retroflex lateral ɭ from the sequence *rt (Payne 1989: 424).

6 The retroflex stops /ʈ, ɖ/ occur in Yidgha in loanwords only (Skjærvø 1989c: 411).

(6)	*Class. Tibetan*	*gloss*	*Modern languages*	
	/grod-pa/	‘belly’	Central Tibetan	/ɖ^{h}ø-pa/
	/drung-du/	‘before’	Central Tibetan	/ʈung-du/
	/p^{h}ru-gu/	‘child’	Central Tibetan	/ʈ^{h}u-gu/
	/krad-pa/	‘leather’	Spiti	/ʈad-pa/
	/k^{h}ron-pa/	‘a spring’	Spiti	/ʈ^{h}on-pa/
	/skra/	‘hair’	Jad	/ʈa/
	/gru/	‘ship’	Jad	/ʈu/
	/bran/	‘slave’	Jad	/ʈan/

It is interesting to note that in these examples not only coronals plus rhotic changed into a retroflex, but also velars and labials plus rhotic.

The examples described in this section show several characteristics of retroflexion in a rhotic context. First of all, the segment to be changed in the rhotic environment does not have to be an apical coronal; it can be laminal, as in Norwegian and Swedish, or even non-coronal, as the developments in the Tibetan languages suggest. Secondly, there is some evidence that the rhotic causing the change can be non-coronal, as Svantesson’s dialect of Southern Swedish show. Thirdly, the direction of influence is not restricted, either; the rhotic might precede or follow the target segment, though retroflexion via preceding rhotics seems to prevail.

4.1.2 Phonetic grounding

Two possible phonetic explanations are proposed here for the change of non-retroflex to retroflex caused by a rhotic, both exemplified in (7) (again, *t* stands for an apical dental/alveolar, and *ʈ* for a retroflex).

(7)	(a)	rt > ɽt > ɽʈ > ʈ	or	tr > tɽ > ʈɽ > ʈ	articulatory explanation
	(b)	rt > ʈ	or	tr > ʈ	perceptual explanation

In (7a), which exemplifies a development in several stages, the first stage is a variation in the place of articulation of a rhotic from dental/alveolar to retroflex. Evidence for such a variation can be found in the fact that quite a number of languages allow a retroflex variant along with their more widespread other rhotic articulation(s). This variant can be either areally restricted, as in British English, where a retroflex [ɻ] is spoken in the South-Western counties of Cornwall, Devon, Somerset, Wiltshire, and Hampshire (Wakelin 1972: 98),[7] or positionally restricted, as in Dutch, where a retroflex variant of the usually apical rhotic can occur in word-final position, according to Goeman & Van de Velde (1999: 99). An example of such a non-restricted change is the Sanskrit retroflex *r* which originates from Indo-European (presumably) alveolar /r/.

Hall (1997a: 215 footnote 21) suggests that an alveolar approximant [ɹ] can easily change to a retroflex approximant [ɻ] because the tongue tip is not inhibited in

7 Wakelin transcribes the British English retroflex rhotic as the flap [ɽ], whereas Ball & Rahilly (1999: 125) refer to this sound as the retroflex approximant [ɻ].

any way during the articulation of the approximant and therefore can retract or even curl backwards. This can result in a retroflex variant. It seems more likely, however, that a change from alveolar to retroflex trill occurs to enhance the perceptual cue of a lowered F3 for the rhotic (see section 3.6 on cue enhancement). Both Hall's and my explanation can account for the context free change of an alveolar /r/ to a retroflex one in American English and, furthermore, for the fact that approximants are the only retroflexes in a number of languages (Bhat 1973).

In some languages, the development of a retroflex variant is followed by assimilation of a non-retroflex adjacent to the retroflex rhotic, see the second stage in (7a), with subsequent drop of the rhotic gesture. Such a development is likely to have occurred in languages where the rhotic is apical and thus can be easily retroflexed. Furthermore, it could have taken place in the diachronic development of retroflexion, where several stages of development are possible. Thus, (7a) can be assumed for the diachronic development of retroflexes in Indo-Aryan and Indo-Iranian, and for the retroflex phonemes in Norwegian and Swedish. Furthermore, the articulatory explanation can account for the above-mentioned development from /rt/ into [ɽ] in Yidgha, where instead of rhotic deletion as assumed in (7a), the stop was deleted. Languages which developed a retroflex in a rhotic context without subsequent deletion of the rhotic, such as Sindhi and Lugbara described above, are further evidence for the staged development as proposed in (7a), since these languages can be assumed not to have undergone the last stage of the development, the rhotic deletion.

The second explanation, given in (7b), is not based on articulation as in (7a). Instead, it refers to the acoustic similarity of rhotic plus non-retroflex and retroflex. Both rhotic and retroflexes share a low third formant (Lindau 1985, Stevens 1998),[8] which could be re-analysed or misparsed by the language learner as belonging to the adjacent coronal segment (specified as [+1F2]), a process Ohala (1993: 89f.) calls "false association parsing error". A schema illustrating this misparsing is given in figure 4.1.

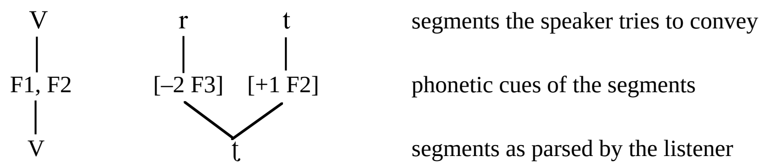

Figure 4.1 Reanalysis of the sequence vowel–rhotic–anterior coronal as vowel plus retroflex (the phonetic cues being, of course, not complete).

[8] Not all rhotics show a lowered F3, though. This is usually a characteristic of coronal rhotics, whereas uvular rhotics show a high F3 (Ladefoged & Maddieson 1996: 244). Ladefoged and Maddieson (ibid.) even mention two cases where retroflex approximant rhotics have a high F3, namely Arrernte and Hausa.

The auditory re-analysis of the rhotic cue makes it possible to economize on the gesture of the rhotic, as it is an additional gesture without perceivable acoustic consequences. This explains the drop of the rhotic after causing the retroflexion, as observable in Scandinavian or Indo-Iranian. Evidence for such a reanalysis of rhotic plus dental/alveolar as a retroflex is the fact that sequences of vowel-rhotic-dental/alveolar are often misperceived as vowel-retroflex sequences (Sharpe 1982: 17).

This second explanation of acoustically similar cues can account for the synchronic processes described in section 4.1.1, as they show a segmental change without any intermediate stages. Furthermore, it can be assumed to account for the retroflexion in Svantesson's (2001) southern Standard Swedish, which is triggered by a uvular rhotic and thus excludes an articulatory assimilation. Both explanations of retroflexion in a rhotic context are formalized in an OT framework in section 6.3.1. It was observed that retroflexion after rhotics is more common than retroflexion before rhotics. This might be explained by the asymmetrical spread of retroflex transitional cues, which have slightly stronger VC cues than CV cues (as described in section 3.5), and are thus more influenced by preceding segments and their cues.

Special attention should be given to the examples in (6) above on the developments from Classical Tibetan, where retroflexion of non-coronals took place. The occurring change of place of articulation from labial or velar to post-alveolar cannot be accounted for by the explanations proposed so far. For this special development, two explanations can be offered. The first one is based again on perception. The acoustic similarity between velars, labials, and retroflexes (see section 3.3.2 and 5.1.1 on Jakobson, Fant & Halle's 1952 feature 'flat') might have caused a reanalysis of velar or labial (plus rhotic) as a retroflex. A second explanation is to assume that there was an intermediate development in Classical Tibetan where the velar or labial changed to an anterior coronal, and only in a subsequent process this anterior coronal followed by a rhotic changed to a retroflex, as in the processes explained above in (7). Such a development would look like /gr/ > /dr/ > /ɖ/. This assumption still cannot explain why a change of labial or velar to anterior coronal should take place. Hence, the explanation based on perceptual similarity between retroflex and velar/labial is preferred here.

Bhat (p. 44) points out that the change from Classical Tibetan was paralleled by the reduction of other initial consonant clusters, where a two- or three-segmental onset was reduced to the last segment of the cluster. This indicates that it might have been the rhotic that changed into a retroflex after the velar, with a subsequent drop of the velar, i.e. a development as described in (7a). Further studies on the diachronic development of initial retroflexes in Tibetan languages are necessary to answer the question of how the retroflex segments emerged in Tibetan. This process will not be further dealt with in chapter 6.

4.2 Patterning with back vowels

In this section the connection between retroflexes and back vowels as given under (1b) is illustrated, where the category of “back vowels” sometimes includes the low vowel /a/, but is often restricted to /u/. Retroflexion in a back vowel context was already the topic of previous studies, among which Bhat (1973), and the data and phonetic grounding of this process given below is largely in line with these studies. Contrary to these former descriptions, it is claimed here that the articulation of retroflexes is closer to that of the mid back vowel [o] than to that of [u], and the fact that [u] is more often the trigger of retroflexion can be accounted for by the larger perceptual similarity between a retroflex and the vowel [u].

The examples in 4.2.1 are mainly from Australian languages, while some instances of Indo-Aryan and American Indian languages are also included. A phonetic explanation for this affinity between back vowels and retroflexes based on articulation is given in section 4.2.2.

4.2.1 Examples

In his description of Australian languages, Dixon (1980) points out that the languages with only one apical (alveolar) of Eastern Australia often have a retroflex allophone after a back vowel. Evidence for the change of alveolars into retroflexes in back vowel contexts comes from the diachronic development of Australian languages. Dixon (1980: 155) reconstructs a single alveolar series of stops, nasals, and laterals for proto-Australian. Cognate sets in languages with one apical (dental or alveolar) and two apicals (dental/alveolar and retroflex) suggest that this single alveolar series in proto-Australian had retroflex allophones after /u/ and alveolar allophones elsewhere. Several West-Australian languages developed contrastive sequences such as [ɑɖ], [iɖ] and [ud], which led to a phonological distinction between apical alveolar and retroflex. This contrast spread to cover almost all languages in the west and the centre. Eastern Australian languages retained one apical, with several of them showing an allophonic distribution as illustrated above.[9] Nyawaygi, spoken on the coast of Queensland between Ingham and Townsville, underwent a diachronic change of apical alveolar to retroflex in back vowel context (Dixon 1983: 449f.). Intervocalically the plosive /d/ became the retroflex flap [ɽ] before *u* and the apical [r] before other vowels.[10] The initial *d* changed to [r], but as this process does not involve a retroflex, it will not be further discussed here. The developments of retroflex and apical flaps can be seen when comparing the language Nyawaygi to its neighbour Wargamay, which retained the original contrasts, see (8).

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9 Dixon (1980: 156) finds evidence for his hypothesis of one alveolar series in proto-Australian in the statistical distribution of phonemes in modern Australian languages. The dictionary of Pitjantjatjara for example shows that after /u/ 53 percent of the apicals are retroflex, whereas after /a/ or /i/ only 39 percent are retroflex.

10 Nyawaygi still has a voiced apical stop in the consonant cluster [nd], but this can be treated as an allophone of the retroflex flap, see Dixon (1980: 148).

(8)		*Wargamay*	*Nyawaygi*	*gloss*
	(a)	wudu	wuɽu	'nose'
		gidul	giɽul	'cold'
	(b)	gadala	garala	'dry'
		baːdi	baːri	'to cry'
	(c)	dubi	rubi	'worm'

In (8a) the Wargamay stop /d/ before the back vowel corresponds to the retroflex flap /ɽ/ in Nyawaygi. (8b) shows that before non-back vowels Nyawaygi has an alveolar. The example in (8c) illustrates that word-initially no retroflex occurs (but a change towards a rhotic).

Even Australian languages that do have apical alveolar and retroflex phonemes sometimes allow a retroflex allophone of the apical alveolar in the /u/ context. The two closely related languages Margany and Gunya spoken in Queensland show a retraction of the alveolar nasal following /u/, so that /guni/, 'to hit' sounds like [guɳi], according to Breen (1981: 288).

The Yadhaykenu dialect of Uradhi, a Northern-Paman Australian language spoken in Queensland, has an apical alveolar lateral which is realized as retroflex flap [ɖ] when following the long back vowels [aː] or [uː], see example in (9a) (from Crowley 1983: 317). When following a short back vowel, lateral and flap are in free variation, see (9b).

(9)				
	(a)	/anaːlu/	[anaːɖuŋ]	'come'-PRES
	(b)	/ipula/	[ipulaŋ] ~ [ipuɖaŋ]	2non-SG-NOM

In the Angkamuthi dialect of Uradhi, the retroflex plosive shows additional frication noise in the form of a rhotic (described by Crowley 1983: 316 as rhotic release). This phenomenon is restricted to contexts where a back vowel follows, see (10).[11]

(10)			
	/antu/	[aɳʈʳuŋ]	'canoe'
	/wuntu/	[wuɳʈʳu]	'crooked'

Besides Australian, several Indo-European languages display a general pattern of retroflexion in a back vowel context. Sinhala, an Indo-Aryan language spoken in Sri Lanka, has a retroflex-dental distinction among apical consonants. Phonetically, the retroflex series varies in place of articulation from retroflex to alveolar (Gair & Paolillo 1997: 11). This variation is phonologically conditioned, so that retroflex consonants are pronounced as retroflex when preceded or followed by back vowels, and as alveolar in most other environments (Karunatillake 1992).[12] In Sri Lankan Portuguese Creole, the dental alveolar nasal and lateral have retroflex allophones

[11] A rhotic or retroflex release also occurs in other Australian languages, as in the Daly language Marrithiyel, where /maʂi/ 'belly' can be pronounced either as [maz̢i] or [maz̢ˡi] (Evans 1995: 739). Evans, though transcribing it with an additional rhotic, describes this phenomenon as r-colouring of the vowel, which could also be interpreted as retroflexion of the vowel, cf. section 4.5.

[12] The question arises why this series is described as 'retroflex' with alveolar allophones, and not the other way round, as the occurrence of the retroflex allophone is far more restricted than that of the alveolar allophone. A reason is probably that this series corresponds etymologically to the retroflex consonants of other Indo-Aryan languages.

after the non-high back vowels [o, ə, a], for instance [aɳimaɭ] 'animal' (Hume & Tserdanelis 2002). Interestingly, the remaining dental-alveolars [t d s z r] do not have such allophones, and the back high vowel [u] is not included in the context.

Some American Indian languages also show an affinity between retroflex sounds and back vowels. In the Molinos dialect of Mixtec, an Oto-Manguean language spoken in Molinos in the Tlaxiaco District of Mexico, the post-alveolar fricatives /ʃ, ʒ/ have retroflex varieties when preceding /a, o, u/, for example *žoʔo* [ʂoʔo] 'rope' or *žą̨ą̨* [ʂoãː] 'very' (Hunter & Pike 1969: 29). When a front vowel follows, the palato-alveolar is realized as such, e.g. *žį̨į̨* [ʃĩː] 'side'.[13] Further Southern American languages having a fricative or an affricate which is changed into a retroflexed one while occurring before back vowels are Acoma, Mazatec, and O'odam (Bhat 1974a: 234). Certain Alaskan languages of the Athapaskan family are described to show a similar behaviour (in the same source).

In the Indonesian language Tolitoli (from the Austronesian language family) an alveolar lateral approximant [l] is in complementary distribution with a retroflex lateral flap [ɭ] (Himmelmann 1991). The data indicate that the retroflex lateral occurs after the back vowels, [o, u, a], see (11a).

(11)	(a)	mo[ɭ]ogo	'wash hands'
		u[ɭ]ag	'snake'
		to[ɭ]ito[ɭ]i	'Tolitoli'
		lelemba[ɭ]an	'to carry'
	(b)	membembe[l]an	'to tremble'
		[l]abia	'sago'
		kiki[l]o	'firefly'

The alveolar lateral seems to occur elsewhere, see (11b).

4.2.2 Phonetic grounding

The phonetic motivation of the affinity between retroflexion and back vowels is both articulatory and acoustic. Back vowels, as their name indicates, are articulated with a backed, i.e. retracted, tongue body, just as retroflexes are, recall the description of retraction as a feature of retroflexes in section 2.3.4. Thus, the cooccurrence of retroflexes in a back vowel context can be seen as a coarticulation process of the dental/alveolar towards the tongue body shape of the back vowels. Bhat (1974a) proposed a similar explanation for the affinity of back vowels and retroflexes.

Since the vowel [o] is articulated with a slightly less raised tongue back and with more retraction (see figure 4.2), it seems as if the back mid vowel is articulatorily closer to the retroflex than [u].[14]

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[13] It coul be argued that the underlying fricative phoneme in Molinos Mixtec is actually retroflex with a palato-alveolar variant in a front vowel context. One indication for this is the writing convention according to which the fricative plus /i/ followed by another vowel is realized as [ʃ], e.g. *žįą̨ʔų̨* [ʃãʔũ] 'fifteen' (Hunter & Pike 1969: 31).

[14] The exact locations of [o] and [u] differ according to the language under investigation. The x-ray tracings of the two vowels in the Akyem dialect of Akan (a Niger-Congo language spoken in Ghana) in Ladefoged & Maddieson (1996: 301) are similar to the cardinal vowels in figure 4.2 on the left. The

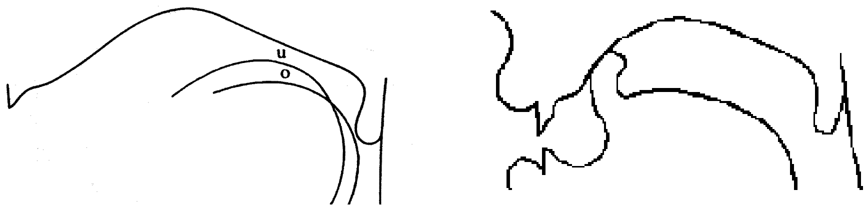

Figure 4.2 Comparison of the tongue back positions for the vowels [o] and [u] (based on x-ray tracings of the cardinal vowels by Catford 1988: 128) on the left with that of a retroflex stop (based on x-ray tracings of a Tamil stop by Ladefoged & Maddieson 1996: 27).

However, only one language could be found that has retroflexion in an [o] context to the exclusion of [u], namely Sri Lankan Portuguese Creole, as illustrated in 4.2.1 above. This strongly suggests that this process is not purely articulatorily motivated.

A further, non-articulatory explanation might be that both retroflexion and back vowels have a lowered F3.[15] The development of retroflexion next to back vowels could be caused by a reassociation of the acoustic cues of backness from vowel to consonant, similar to that of the reassociation of rhotic cues illustrated in section 4.1.2. This explanation is expected to hold especially for back, rounded vowel context, as rounded back vowels show a particularly low F3. Some languages such as Molinos Mixtec or the Yadhaykenu dialect of Uradhi show retroflexion of consonants with a following back vowel, which indicates that the CV transitional cues for retroflexes are important and distinctive enough to allow such a re-association, recall the discussion of asymmetricality of retroflex cues in section 3.5.

Looking at the manner of articulation of those segments that change into a retroflex in the languages discussed here, it is mainly nasal, lateral, and rhotic dentals/alveolars that are influenced as the single segments in languages by the back vowel context. In the Australian languages, this restriction holds for Nyawaygi, Margany, and Gunya; furthermore, it can be observed in Sri Lankan Portuguese Creole and in the Indonesian Tolitoli. In some languages, the whole dental/alveolar series is retroflexed, as in Sinhala and the Angkamuthi dialect of Uradhi. An account for this can be given by the different inherent cues of the manner classes involved. Sonorants like nasals, laterals, and rhotics have continuous formants just like the adjacent vowels. Instead of a clearcut borderline between the vowel formants and those of the sonorants, a smooth transition is given in these segment sequences. It is therefore more likely that a hearer misaligns a low F3 in the context of liquids than

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tracings of these vowels in Even (Ladefoged & Maddieson 1996: 307), a Tungus language of North-Central Siberia, however, show that both vowels have the same degree of backing and differ only in the degree of lowering. This interaction of retroflexes with the two back vowels is a topic that has to be left open for future research.

[15] The acoustic cues shared by retroflexion and back vowels certainly cannot be treated as independent of the articulatory similarity: retraction of the tongue body causes a lowering of F3, as described in section 3.2.4.

in that of for instance a stop, where only short vowel transitions are available followed by the silence of the stop closure. For a formal account of this difference see section 6.3.2.

One systematic exception to this observation are American Indian languages such as Molinos Mixtec and Mazatec (Oto-Manguan languages), Acoma (Keresan language), and O'odam (Uto-Aztecan) in which a fricative or affricate are the only segments to be retroflexed in a back vowel context. This is in line with the general tendency of American Indian languages to show retroflexion of fricatives and affricates only.

Further instances of the interaction of retroflex segments with back vowels are given in subsection 4.3.2.1 below where front vowels are changed into back ones in a retroflex environment due to a dislike of the gestures of retroflexion and front vowels.

4.3 Non-occurrence of retroflexes in front vowel context

As was already indicated in section 4.2.2, the front vowel context is avoided by retroflex segments. This avoidance can be observed in a large number of languages, but it is not a universal principle as there are languages where retroflexes do occur in a front vowel context. The dispreference of retroflexes for the front vowel context is realized in a number of avoidance strategies, recall the description in (1c) which gave two outputs, namely [it] or [ɨʈ]. These two illustrate the two main strategies that languages employ to avoid the dispreferred sequence, namely a change of the retroflex into an anterior coronal (i.e. the front high vowel gesture dominates), repeated here in (12), and to change the front vowel (i.e. the retroflex gesture dominates). The change of the front vowel can take on several forms: (13a) vowel retraction, (13b) vowel lowering, (13c) vowel diphthongization, or (13d) vowel rounding.

		input	*output*	*process*
(12)		/iʈ/	[it]	de-retroflexion
(13)	(a)	/iʈ/	[ɨʈ] or [ɯʈ]	retraction
	(b)	/ɛʈ/	[æʈ]	lowering
	(c)	/iʈ/	[iəʈ]	diphthongization (schwa insertion)
	(d)	/iʈ/	[yʈ]	rounding
(14)	(a)	/ʈʲ/	[t̠ʲ]	de-retroflexion
	(b)	/ʈʲ/	[ʈ]	de-palatalization
	(c)	/ʈʲ/	[ʈj]	separate palatal realization

Due to the articulatory similarity between high front vowels and the front glide /j/, the present illustration includes a short discussion on the incompatibility of retroflexes with secondary palatalization, recall the development of this assumption in section 2.5. In (14) the avoidance strategies for secondary palatalization are given: a change into a non-retroflex coronal with secondary palatalization (14a), into a non-palatalized retroflex (14b), or realization as a separate palatal glide (14c).

The examples given below are subdivided accordingly: section 4.3.1 deals with processes such as (12), section 4.3.2 with processes like (13), and section 4.3.2.5 with those in (14). Mandarin, Polish and Russian are shown to apply one of these strategies, and thus provide phonological evidence for the retroflex status of their fricatives (recall discussion in 2.4): Mandarin retroflexes occur only in a non-front vowel context, see 4.3.1 below, and Polish and Russian centralize a following /i/, cf. section 4.3.2.1. The phonetic grounding of the avoidance strategies is discussed in section 4.3.3. Section 4.3.4 deals with a counterexample for front vowel avoidance, namely the *ruki* rule, where retroflexion occurs precisely in front vowel context.

4.3.1 De-retroflexion in front vowel context

In section 4.2 it was shown mainly for Australian languages that retroflexes are often in complementary distribution with other coronal segments (apical alveolars for example), where the retroflex consonants occur in a back vowel context, and the other coronal series in a front vowel context. Several other languages also show this pattern. In Karok, for example, a Northern Hokan language spoken in Northwestern California (around the Klamath river), the retroflex segments [ʂ̻, ʈʂ̻] are in (near) complementary distribution with the palato-alveolars [ʃ, t̠ʃ].[16] The retroflex fricative and affricate do not occur after the front vowel [i] even if other consonants intervene, while in this same environment palato-alveolars do occur, see the examples in (15) with retroflexes in the first column and palato-alveolars in the second (from Bright 1957).[17]

(15)	[ʂ̻ara]	'bread'	[pikʃip]	'shadow'
	[ʔaʂ̻ʂ̻ak]	'on a rock'	[tujʃip]	'mountain'
	[ʔaːʂ̻]	'water'	[t̠ʃiːʃ]	'younger sister'

As a result of this complementary distribution, morphological processes cause a change from retroflex to palato-alveolar after a sequence of front vowel and /p/, see (16a), and from palato-alveolar to retroflex after a mid or back vowel, see (16b).

(16)	(a)	/ʔarip+ʂ̻uru/	[ʔaripʃuru]	'to cut a strip off'
		/pəhip+ʂ̻uruk/	[pəhipʃuruk]	'under the pepperwood'
	(b)	/mu+iʃpuka/	[muʂ̻puka]	'his money'
		/ʔu+iʃkak/	[ʔuʂ̻kak]	'he jumps'

Acoma, a Keres language spoken in New Mexico, shows a similar complementary distribution, here the retroflexes change to alveolar or palato-alveolar before front vowels (Miller 1965). The same process occurs in Molinos

[16] Exceptions to this allophonic distribution are some loanwords which allow a front vowel-retroflex sequence, e.g. [ʂ̻ikspiʈʂ̻] 'six bits', and reduplicated forms such as e.g. [taʂ̻inʂ̻ir] 'to brush repeatedly' from /taʂ̻ir/ (Bright 1957: 44). Bright further reports that nouns plus a possessive prefix allow some idiolectal variation, thus /nani-ʂ̻ara/ 'my bread' can be realized either as [naniʃʃara] or [naniʂ̻ʂ̻ara].

[17] The restriction for retroflexes seems also to hold before non-high front vowels, as no words containing a sequence retroflex-front vowel could be found in the data.

Mixtec (Hunter & Pike 1969). Another Amerindian example is the Pano-Tacanan language Chácobo spoken in Bolivia, in which the retroflex [ʂ] does not surface in words when preceded or followed by the front vowel [i]. In this case, the palato-alveolar [ʃ] occurs (Prost 1967: 62).

Further evidence for the cross-linguistic validity of retroflexes dispreferring the front vowel context comes from the Sino-Tibetan language group. Khonoma Angami, a Tibeto-Burman language spoken in the Naja Hills in the North-Eastern parts of India, has a retroflex approximant [ɻ] and a voiceless counterpart of this. According to Blankenship, Ladefoged, Bhaskararao, & Chase (1993: 132), the retroflex approximant is laminal before high vowels and subapical otherwise. The laminality indicates that this allophone is not retroflex, recall the retroflex criterion of apicality as introduced in section 2.3.1.[18]

In several Chinese dialects the retroflex fricative and affricate series (and also the dentals and velars) do not occur before a high front vowel, whereas the alveolo-palatals occur only in these positions (Yip 1996). Table 4.1 illustrates these phonotactic restrictions.

Table 4.1 Cooccurrence restrictions in Mandarin and other Chinese dialects (Yip 1996).

	_aj	_u	_i	_y
ʈʂ, ʂ	√	√	*	*
tɕ, ɕ	*	*	√	√

This evidence for the incompatibility of Chinese post-alveolar fricatives and affricates supports the claim made in chapter 2 that these sounds are retroflex on articulatory grounds.

Diachronic evidence for the avoidance of retroflexes in a front vowel context can be found in the Indo-Aryan language Gujarati, where [ʂ] became alveolo-palatal [ɕ] before front vowels, but stayed retroflex elsewhere (Pandit 1954).

4.3.2 Change of front vowels in retroflex context

This section discusses and exemplifies several processes of how a front vowel is changed in a retroflex context. The processes found in natural languages are retraction, lowering, diphthongization, and rounding of front vowels, see (17a) – (d).

(17)

	input	*output*	*process*
(a)	/iʈ/	[ɨʈ] or [ɯʈ]	retraction
(b)	/ɛʈ/	[æʈ]	lowering
(c)	/iʈ/	[iəʈ]	diphthongization (schwa insertion)
(d)	/iʈ/	[yʈ]	rounding

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[18] As coronal rhotics are almost always apical (see Hall 2000a), the segment occurring before high front vowels is expected to show a manner change towards a non-rhotic, as well. No indication for this could be found in Blankenship et al.

Vowel retraction, lowering, diphthongization, and rounding will be illustrated in sections 4.3.2.1, to 4.3.2.4, respectively. Often more than one of these processes occurs simultaneously in one language.

4.3.2.1 Retraction of front vowels

The first avoidance strategy modifying the vowel, namely retraction of front vowels (17a), is observable in the Dravidian vowel system. Zvelebil (1970: 38) notes that Iruḷa shows retraction of the front vowel /i/ to the central [ɯ] before a retroflex consonant. Likewise, the front vowel /e/ is retracted to [ɤ] in this environment. As a consequence the high and mid back unrounded vowels (graphically represented as *ï* and *ë*) were added as phonemes to the general Dravidian five-vowel system *i, e, a, o, u*. The backing of front vowels can also be found in the South-Dravidian language Koḍagu (also called Kodava) spoken in the Coarg district (Zvelebil 1970, Emeneau 1970, Ebert 1996). Here the vowels /i/ and /e/ are backed before the retroflex consonants /ʈ , ɖ , ɳ , ɭ/. The phonetic representations of the outcome of this change differ: Gnanadesikan (1994) uses the symbols [ɨ] and [ɘ], whereas Ebert represents them as [ɯ] and [ʌ], implying a more extreme retraction.[19]

Gnanadesikan (1994: 132) compares Koḍagu with other Dravidian languages to exemplify the change, given here with additional examples (based on Zvelebil 1970) in (18), where (a) involves backing in non-labial context, and (b) backing and rounding after labials.

(18)		*Koḍagu*	*Other Dravidian languages*		
	(a)	ɨɭi	iɭi	(Tamil, Malayalam, Kannada)	'to descend'
		ɘɳɳ-	eɳɳu	(Tamil)	'to say' in Koḍagu 'to count' in Tamil
		kɘːɭ	keːɭ	(Tamil)	'to hear'
	(b)	puɖi	piʈi	(Tamil, Malayalam)	'to catch hold'
		puɳɖ	piɳɖu	(Kannada)	'to squeeze'
		poɳɳɨ	peɳ	(Tamil, Malayalam, Kannada)	'wife, female'

The backing of vowels after labials and before retroflexes can also be observed in Colloquial Tamil, e.g. /viːɖɯ/ can be pronounced as [vɘːɖɯ] (Zvelebil p. 47f., Bright 1975: 15).[20] Toda, a Dravidian language spoken in the Nilgiri Hills in Southern India, is a further example for a language that has a process of vowel retraction in a retroflex context (Zvelebil 1970: 46). Here, Proto-Dravidian *i changed to [ɯ], e.g. 'mountain' is [tɯʈ] in Toda but [tiʈːu] in Tamil, and Toda [kɯɽ] 'small' is Tamil [kiɽu].

[19] Zvelebil (1970) uses only the diacritic [¨] above *i* and *e* to symbolize their retraction, but gives no indication for the amount of backing. Bright (1975: 16) explains that the retracted *i* is similar to the underlying back [ɯ].

[20] Bright explicitly points out the difference between the two vowels in this example, the first one being central, the second back.

Several members of the Australian language family show vowel retraction. For instance, Bunuba (Rumsey 2000), spoken in Western Australia, realizes the phoneme /i/ as high central vowel [ɨ] before retroflexes, see (19).[21]

(19)	/biɖi/	[bɨɖi]	'upper leg, thigh'
	/giɭiɭi/	[gɨɭiɭi]	'shoulder blade'
	/dʒiɽʌli/	[dʒɨɽʌli]	'before, long ago'

Wembawemba, an Australian language spoken in Victoria (Hercus 1986: 17; Flemming 2002: 91), shows retraction of front vowels: The mid front vowel /e/ is retracted if preceding a retroflex, see the examples in (20).

(20)	/peɳeɽ/	[pɜɳɜɽ]	'teal duck'
	/meʈmeɽil/	[mɜʈmɜɽil]	'large black cormorant'
	/weɽpuk/	[wɜɽpuk]	'tree trunk'

This vowel retraction is accompanied by vowel lowering as described in section 4.3.2.2 below. The high front vowel /i/ in Wembawemba undergoes rounding and lowering before retroflexes, cf. section 4.3.2.4.

Vowel backing occurs also in the Micronesian language Ponapean (Rehg 1973, Gnanadesikan 1994: 133), where the front vowels /i/ and /e/ surface as backed after retroflexes (and other consonants referred to as 'back' in Rehg), see (21a) below. Back vowels remain unchanged in this environment, see (21b).

(21)	(a)	ɽɨɽ	'secret'	(b)	ʈʂop^{w}	'lush'
		ʈʂəŋ	'tight'		ɽɔŋ	'burned'

The Chinese language Pingding (Lin 1989) has a process whereby the retroflex lateral [ɭ] is inserted after the initial consonant of the stem to denote familiar usage (originally this infix had diminutive meaning). The process triggers a change in the following front vowel towards a back vowel, see (22a), or a loss of the front high vowel, see (22b) (Lin 1989: 187).[22]

(22)	(a)	/tɕʰyæ̃/	[tsʰɭua]	'circle'
		/ʂəu tɕyæ/	[ʂəu tsɭua]	'handkerchief'
	(b)	/tɕiəŋ/	[tsɭəŋ]	'now'

Polish post-alveolar fricatives and affricates show a retraction of vowels similar to that illustrated up to now, and thus give support to their articulatory analysis as retroflexes in chapter 2. The process in Polish whereby /i/ surfaces as the central high vowel [ɨ] after hard (i.e. velarized) dentals and retroflexes is called 'retraction rule' (Booij & Rubach 1987:16ff.; Rubach 1995: 858ff., Hall 1997: 44). Examples of this rule are given in (23) with the verbalizing suffix /i/.

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21 Interestingly, the retraction of front vowels is also triggered by velars in Bunuba, see e.g. /miŋʌli/ 'hand' is realized as [mɨŋʌli] (Rumsey 2000: 44).

22 The cooccurring change from alveolo-palatal to alveolar affricate is due to the allophonic restriction of alveolo-palatals to appear in front vowel contexts only, cf. 4.3.1 above.

(23)	towarzy**sz**+**y**+ć	[tovaẓɨ̢ʂɨtɕ]	'to accompany'
	stra**sz**+**y**+ć	[straʂɨtɕ]	'to frighten'
	miażd**ż**+**y**+ć	[mʲaẓdẓɨtɕ]	'to squash'

The same behaviour of vowel retraction can be observed for the Russian post-alveolar fricatives. Like the Polish segments they do not occur in front vowel context. Only the central vowel /ɨ/ is allowed after these sounds (Hamilton 1980), see the occurring pronunciations in the first row of (24) with the impossible ones in the second row.

(24)	[ʂɨɫ]	*[ʂiɫ]	*šil*	'he sewed'
	[ẓɨɫ]	*[ẓiɫ]	*žil*	'he lived'

Based on these data I assume a cooccurrence restriction for Russian that disallows sequences of retroflex fricatives and front high vowels, phonologically supporting the fricatives' retroflex status.

4.3.2.2 Lowering of front vowels

Norwegian has a rule of *e*-lowering before retroflexes. Examples of this process are given in (25), where the first column contains words with /ɛ/ or /eː/ followed by a dental, and the second column contains an /ɛ/ followed by a retroflex, where the vowel is realized as [æ] (based on Kristoffersen 2000:14, 105f.).[23]

(25)	[ʋɛt]	*vett*	'intelligence'	[ʋæʈ]	*vert*	'host'
	[hɛlg]	*helg*	'weekend'	[hæɽj]	*helg*	less formal register
	[heːl]	*hæl*	'heel'	[hæːɽ]	*hæl*	less formal register

With respect to [ʂ], Norwegian shows variation, cf. [hæʂ.ʂə] *herse* 'to bully' vs. [hɛʂ.ʂə] *hesje* 'haydrying rack', but in most cases [æ] is found (ibid.).

In Svantesson's (2001) Southern Swedish dialect, vowel lowering of [ø, ʉ, o, ɛ] (and the long counterparts) occurs before 'retracted' coronals, which is an indication of the retroflex nature of these consonants (recall discussion in 4.1 above). Examples of this process are given in the first column of (26), compared to unaffected vowels in non-retroflex environment, see the second column.

(26) (a)	[hœːʂ]	*hörs*	'is heard'	[høːs]	*hös*	'hay's'
	[bɵːʂ]	*burs*	'cage's'	[bʉːs]	*bus*	'mischief'
	[læːʂ]	*lärs*	'is learned'	[lɛːs]	*läs*	'read'
(b)	[bœəʂ]	*börs*	'purse'	[løs]	*löss*	'lice'
	[kɔəʈ]	*kårt*	'short'	[skot]	*skott*	'shot'
	[væʈ]	*värt*	'worth'	[vɛt]	*vätt*	'wett'
(c)	[lɐːʂ]	*Lars*	(name)	[laːs]	*las*	'was laid'

In (26a) the lowering of high and middle long vowels is illustrated. In (26b) the respective short vowels are lowered. All the short vowels apart from [ɛ] show

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[23] The apical tap [ɾ] also triggers vowel lowering, e.g. [tʋæɾ] *tverr* 'cross' (adj.), which is unexpected, since it is not retroflex.

additional schwa insertion. (26c) shows that the long [a] is raised in a retroflex context whereas the short [a] remains unchanged, cf. *kart* [kaʈ] ‘unripe fruit’.

In the Australian language Kayardild (Evans 1995: 58f.), a following retroflex causes lowering and retroflexion of the high vowels [i] and [u]: *birdiy* [beʳɖej] ‘bad’ and *kuru* [koʳɽɯ] ‘egg’. The two Pama-Nyungan languages Margany and Gunya (Breen 1981: 289) also show lowering of both high vowels (plus retraction in the case of the front vowel) before all retroflexes, see the examples in (27), where (a) illustrates the change for the high front vowel, and (b) for the high back vowel.[24]

(27)	(a)	/badbiɖa/	[bɐɾbɨɖɐ] ~ [bɐɾbəɖɐ]	‘porcupine’
		/nikiɭ/	[nikəɭ]	‘hot coal’
	(b)	/juɖi/	[joɖi]	‘meat’

Lowering of vowels when adjacent to retroflexes also seems to occur in the Dravidian languages Tamil, Malayalam, and Kannada. Here, standard forms with /o/ alternate with more substandard forms such as /u/, e.g. [koʈu] ~ [kuʈu]. Zvelebil (1970: 63) mentions that there is some evidence that the forms with /u/ are older than those with /o/, and thus vowel lowering before retroflexes took place in the standard languages.

4.3.2.3 Diphthongization of front vowels

Diphthongization is a further strategy applied to avoid the sequence high front vowel – retroflex. Schwa-insertion resulting in a diphthong occurs for example in the Beijing dialect of Chinese. A high front vowel – retroflex sequence might occur in Beijing by the morphological process of [ɻ] suffixation (Lin 1989), which has the same meaning of indicating familiar usage as the retroflex infix in Pingding illustrated earlier in (22). If the stem ends in a front high vowel, then a schwa is inserted between stem and suffix, see the examples in (28a) compared to those in (28b) where no insertion takes place (from Lin p. 188).

(28)	(a)	/pʰi + ɻ/	[pʰiəɻ]	‘skin’
		/y + ɻ/	[yəɻ]	‘fish’
	(b)	/xua + ɻ/	[xuaɻ]	‘flower’

In the Australian language Gugada spoken in Queensland, the transitions of vowels into the retroflex are lengthened, and the vowel quality is changed into a lower, backer vowel (Platt 1972). This results in a schwa-like segment before the retroflex. Platt transcribes the result as [ɪə].

In Svantesson’s (2001) Southern Swedish dialect, vowel diphthongization of the high vowels [i, y, u] (long and short) and the mid vowels [eː, ø, o] occurs before all retroflexes.[25] These diphthongized vowels are realized with the same quality as their non-diphthongized equivalents, but with a schwa-like offglide of the vowel. Examples of this are in (29) (Svantesson 2001: 157), with non-diphthongized equivalents in the second column.

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[24] The second example, /nikiɭ/, exists only in Margany, the other two in both languages.

[25] Recall the discussion in section 4.1 whether the segments causing this process are retroflexes or not.

(29)	[hiəʂ]	*hirs*	'millet'	[his]	*hiss*	'lift'
	[piːəʂ]	*pirs*	'pier's'	[biːs]	*bis*	'bee's'
	[syəʂa]	*syrsa*	'cricket'	[systə]	*syster*	'sister'
	[bœəʂ]	*börs*	'purse'	[løs]	*löss*	'lice'
	[kɔəʈ]	*kårt*	'short'	[skot]	*skått*	'shot'
	[kuəʈ]	*kort*	'card'	[skut]	*skott*	'shoed'
	[kuːəʂ]	*kors*	'cows''	[kɪuːs]	*kos*	'cow's'
	[eːəʂ]	*ers*	'your'	[eːs]	*es*	'e's'

Not all of the Southern Swedish vowels as described by Svantesson undergo diphthongization before retroflexes; the long non-high vowels and [ɛ] show lowering (recall section 4.3.2.2). The short vowels /ø/ and /o/ are both lowered and diphthongized, resulting in /œə/ and /ɔə/, respectively.

4.3.2.4 Rounding of front vowels

Wembawemba, which was illustrated to have backing of vowels in (20) above, also has a process whereby the vowel /i/ is rounded if it precedes retroflex consonants (Hercus 1986, Flemming 2002: 89ff.), see (30).

(30)	/t̪ʲiɳʈ̪ʲiɭ/	[t̪ʲyɳʈ̪ʲyɳ]	'poker'
	/tiʈənaiuk/	[tyʈənaiuk]	'new, fresh'
	/miɽkuk/	[myɽkuk]	'egg'

Rounding in Wembawemba does not occur in the absence of a retroflex, see for example the word for 'tomahawk', /tir/, which is realized as [tir]. A similar process of vowel rounding can be found in Wergaia (Hercus 1986, Flemming 2002: 90), a language that is closely related to Wembawemba, see examples in (31).

(31)	/giɽəm/	[gyɽəm]	'spear shield'
	/d̪ʲiʈuk/	[d̪ʲyʈuk]	'end'

Retroflexes also condition the rounding of vowels in South-Dravidian languages. Iruḷa, for example, shows a diachronic development from /a/ to [ø] and from /e/ towards [ɯ] or [ø], triggered by a retroflex that was partly lost, as comparisons with Tamil words show, see (32) (based on Zvelebil 1970: 44, 59, 64).[26]

(32)	*Iruḷa*	*Tamil*	*gloss*
	[køtːu] ~ [køtu]	[kaɭutːu]	'neck, throat'
	[kɯʈːa]	[keʈːa]	'bad'
	[øːɭdu]	[eɭutu]	'to write'

Bright (1975: 23) describes these vowels as retracted only; no mentioning is made of rounding. Considering Bright's very precise descriptions of Dravidian vowels (recall

[26] The Iruḷa vowels also show raising, which probably occurred independently of the retroflex context, as no other language to my knowledge shows vowel raising in retroflex context. The raising is not phonetically motivated and is therefore not further discussed in this dissertation.

footnotes 19 and 20), it does not seem accidental that he does not mention any rounding of the Iruḷa retracted vowels. Further support for this non-rounded description of the retracted vowels in Iruḷa is Diffloth (1975: 55), who describes these segments as “centralized (or retroflexed) vowels”. Following Bright and Diffloth, I assume that the vowels in Iruḷa are not rounded and will therefore not further treat the Iruḷa data in this dissertation.

In Koḍagu, another South-Dravidian language, the process of vowel backing is accompanied by vowel rounding when the preceding vowel is a labial, as illustrated already in (18). This process can be further illustrated when compared to other Dravidian languages: Proto-Dravidian */e:/ is changed to an /o:/ in Koḍagu, cf. [boːʈe] ‘hunting’ compared to Tamil [veːʈːai] ‘id.’, or Koḍagu [poːɽ] ‘to transport by pack-animal’ vs. Kannada [peːɽu] ‘to load’ (Zvelebil 1970: 61).

4.3.2.5 Retroflexion and secondary palatalization

Secondary palatalization of retroflexion, as discussed already in section 2.5, shows three avoidance strategies, namely change of the retroflex into a laminal palatalized coronal, non-palatalization of the retroflex, or sequential realization of retroflex and palatal glide. All three processes are illustrated here in (33).

(33)	*input*	*output*	*process*
(a)	/ʂʲ/	[ʃʲ]	de-retroflexion
(b)	/ʈʲ/	[ʈ]	de-palatalization
(c)	/ʈʲ/	[ʈj]	separate palatal realization

In section 2.5 de-retroflexion as in (33a) was assumed to take place in Polish and Russian, where /ʂʲ/ surfaces as an inherently palatalized laminal palato-alveolar [ʃ].

Resistance towards secondary palatalization as exemplified in (33b) can be found in Scots Gaelic, where nouns usually undergo palatalization in the genitive singular, recall the example [kʰatʰ] ‘cat’ (nom. sg.) versus [kʰat̠ʰʲ] ‘cat’ (gen. sg.) from section 2.5.1. Nouns with retroflex consonants remain unpalatalized, e.g. [paːʈ] ‘a poet’ (both nom. and gen. sg.) (Borgstrøm 1940: 76).

As described in section 2.5.2, Toda has palatalized retroflex rhotics such as [oɽʲ] ‘foot’, or [toɽʲ] ‘pole used at funeral’ (Spajić et al. 1996). In the same section acoustic evidence was given for the claim that these allegedly palatalized retroflexes are realized as retroflexes with a following front glide.

4.3.3 Phonetic grounding

The previous sections contained several processes illustrating that retroflexes disprefer front vowel context and secondary palatalization. The processes applied to avoid these segments or segment sequences are repeated here in (34), (35), and (36).

		input	*output*	*process*
(34)		/iʈ/	[it]	de-retroflexion
(35)	(a)	/iʈ/	[ɨʈ] or [ɯʈ]	retraction
	(b)	/ɛʈ/	[æʈ]	lowering
	(c)	/iʈ/	[iəʈ]	diphthongization (schwa insertion)
	(d)	/iʈ/	[yʈ]	rounding
(36)	(a)	/ʈʲ/	[t̠ʲ]	de-retroflexion
	(b)	/ʈʲ/	[ʈ]	de-palatalization
	(c)	/ʈʲ/	[ʈj]	separate palatal realization

Whereas sequences of front vowels and retroflexes actually occur in natural languages, it was claimed in section 2.5 that retroflexion with a secondary palatalization is articulatorily impossible and therefore does not occur in any language. Despite this difference, both the dislike of retroflex and front vowels and the absolute incompatibility of retroflexion and secondary palatalization have the same articulatory grounding: a flat tongue middle and retracted tongue back configuration for retroflexion cannot be combined with the high tongue middle and fronted tongue back necessary for both front vowels and palatalization. A simultaneous production of both gestures as in secondary palatalization is impossible, and a sequential order such as retroflex and high front vowel or high glide is dispreferred, because it involves a major movement of the tongue from one extreme position (namely a high fronted position) to the other (the backed, velarized position).[27]

The articulatory distance between the two positions can be reduced by a number of mechanisms. First of all, the retroflex gesture can be reduced, resulting in a non-retroflex coronal, as in (34) and (36a). Secondly, the gesture of the vowel or the glide can be reduced. For the glide, only a total deletion can be observed in the languages of the world (see 36b), probably because a partial reduction is not recognizable as secondary palatalization anymore.[28] For the front high vowel, several articulatory reductions are possible which facilitate the transition to a retroflex gesture: the vowel can be retracted (35a), or lowered (35b), or both; or diphthongization of the vowel can occur (35c).

Vowel retraction or lowering involves a departure from the underlyingly specified vowel quality. The vowel realized instead has a tongue position that is closer to that of the adjacent retroflex, and thus diminishes the distance between vowel and consonant gestures. Only high vowels are target of lowering, and front vowels target of retraction.

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[27] The articulatory argumentation of a dislike for high front vowels and a backed, velarized position is not restricted to retroflexion. It can also explain why velars always have a fronted allophone when adjacent to front high vowels.

[28] Only one case of front vowel deletion in retroflex context could be found, namely Pingding Chinese, recall the examples in (22b).

Diphthongization involves the movement from the high front vowel to some kind of neutral position (or a position as in a retracted or lowered vowel) before the tongue position for the retroflex is assumed. Only high or mid front vowels are a target of this process. The vowel and the retroflexion gestures show a gestural delay, as illustrated in figure 4.3.

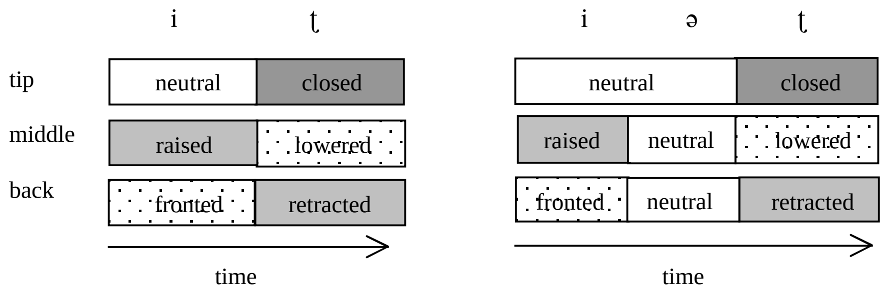

Figure 4.3 Gestural timing of vowel – retroflex sequences, without delay on the left, and with delay and resulting vowel diphthongization on the right. The three tiers indicate the three tongue parts tip, middle, and back. The tongue blade is not included, since it is not relevant for the depiction of this process. Neutral position of the tongue parts is depicted with white boxes, a positive degree of constriction i.e. raising of the articulator with a grey box (dark grey standing for full closure), and negative constriction i.e. lowering of the articulator with a dotted box.

Rounding of a vowel, see (35d), is obviously not a process that facilitates the articulation of front high vowel – retroflex sequences, since both retroflexion and rounding are produced with independent articulators, namely the tongue and the lips, respectively, and therefore do not affect each other. This process can be motivated by two different explanations. In Koḍagu vowel rounding seems to be caused by the adjacent labial consonant, and not by the retroflex. The articulation of a rounding gesture is rather slow; according to Stevens (1998: 44) the minimal time from a rounded to an unrounded configuration of the lips is 50 to 100 ms. This slowness can account for the fact that the lips are still not in neutral position at the beginning of the vowel, which can subsequently lead to a rule of full vowel rounding after labial consonants, a process that is cross-linguistically quite common.

Vowel rounding in Wembawemba and Wergaia, however, cannot be articulatorily motivated since it is not caused by adjacent labials. Flemming (1995 [2002], 2001) proposes that the rounding in a retroflex context in these languages is the result of a reduction of the retroflex gesture (process (34)) with concomitant rounding of the vowel in order to preserve the perception of a low F3 typical for a retroflex (section 5.3.2 below gives a summary of Flemming's analysis). This perceptual preservation seems plausible: the listener can interpret the lowered F3 of the rounded vowel as belonging to the coronal consonant as illustrated in Figure 4.4.

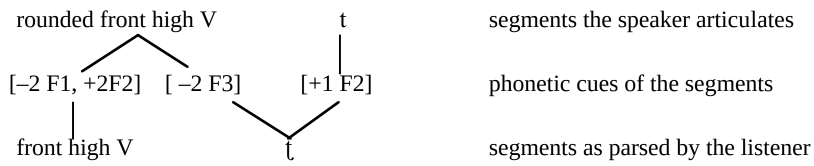

Figure 4.4 Listener's interpretation of the sequence rounded front vowel – alveolar as (rounded) front vowel–retroflex (illustration of Flemming's proposal).

Flemming, though, fails to explain why the rounding is realized on the vowel and not on the consonant, since it is the retroflexion of the consonant that is supposed to be enhanced by rounding. The shift in target segment can be explained by the fact that rounding on consonants is perceptually not as salient as rounding on vowels. Especially stop articulations yield only transitional perceptual cues for rounding, since no continuous formant cues during the consonant are available. In addition, the slowness of the labial gesture probably causes distinct labialization cues only halfway of the consonant. If, on the other hand, in a vowel-consonant sequence as in Wembawemba or Wergaia the rounding configuration is assumed for the vowel, perceptual cues of rounding are available throughout the vowel. Therefore rounding is more effective if realized on the preceding vowel instead on the retroflex itself.[29] Both the articulatory and the perceptual motivation for the rounding processes will be formalized in section 6.3.3.4.

Whereas for diphthongization the vowel and consonant gestures show delay, in vowel retraction and lowering there occurs some overlap in gestures; the tongue position is changed already during the vowel. This gestural overlap provides the listener with additional cues for retroflex articulation, though at the cost of the vowel cues.

It is assumed here that languages requiring very precise vowel cues, such as languages with large vowel inventories, do not allow articulatory assimilations of retroflex and front vowels with resulting changes in the perceptual cues of the vowels, because it would reduce the perceptual difference between the single vowels and thus risk perceptual confusion. Evidence for this assumption can be found in the fact that mainly languages with very small inventories, such as the Australian Margany, Gunya, and Bunuba with the vowels [i, a, u] (short and long) allow the processes in (35). An assimilation mechanism acceptable for large vowel inventories is diphthongization, see (35c), because it preserves at least part of the cues of the original vowel. The large vowel inventory of Swedish, for example, mainly undergoes diphthongization before retroflexes (see (26) and (29)).

Having established the phonetic motivation of the processes involving high vowel and retroflex sequences, we can now inspect the contextual position of the

[29] The present argumentation does not exclude the possibility that rounding occurs on both the vowel and the consonant.

segments undergoing the changes, and the manner of the retroflexes involved. The list in (37) – (41) gives a summary of this information from the examples given above, where *R* stands for the class of retroflexes and *L* for labials:

	vowel	retroflex	language
(37)	*de-retroflexion (section 4.3.1)*		
	i_	ʂ, ʈʂ	Karok, Acoma, Molinos Mixtec
	_i_	ʂ, ʈʂ	Chácobo
	_i	ʂ, ʈʂ	Khonoma Angami, Chinese, Gujarati
(38)	*retraction (section 4.3.2.1)*		
	i e	_R	Iruḷa, Koḍagu, colloqu. Tamil, Toda
	i e	ɽ, ʈʂ _	Ponapean
	i	_R	Bunuba
	e	_R	Wembawemba
	i	ʂ _	Russian, Polish
	y	ɭ _	Pingding Chinese
(39)	*lowering (section 4.3.2.2)*		
	e	_R	Norwegian
	ɛ ɛː oː øː ʉː	_R	Swedish
	i u	_R	Kayardild, Margany, Gunya
	u	_R	Tamil, Malayalam, Kannada
(40)	*diphthongization (section 4.3.2.3)*		
	i	_ɻ	Beijing Chinese
	i	_R	Gugada
	high Vs + eː ø o	_R	Swedish
(41)	*rounding (section 4.3.2.4)*		
	i	_R	Wembawemba, Wergaia
	e	L_R	Koḍagu (plus retraction)

The process of palatalization is not included here, because it differs from the vowel – retroflex sequences in that it always involves a palatalization context, i.e., a high front vowel, which usually follows the consonant.

In general, it can be observed that the retroflexes involved in the processes are almost always the whole retroflex class of the specific language. In some cases I specified the retroflex class of specific languages, as for Russian, Polish and Ponapean, to show the restricted set of retroflexes in these languages. The only exceptions to this are the Beijing Chinese rhotic and the Pinging Chinese lateral, which are not the only retroflexes in these languages, but the only segments involved in the processes. This is due to the morphological conditioning of the processes: diphthongization in Beijing occurs only after the suffixation of the retroflex rhotic, and backing in Pingding occurs only after infixation of the lateral retroflex.

The direction of influence is often from retroflex to preceding vowel. Vowel lowering and rounding occurs only before retroflexes in our examples. This behaviour is in accordance with the stronger cues of retroflexion leading into the segment (VC cues) than those leading out of it (CV cues), as illustrated in section 3.5. Furthermore, some studies (e.g. Krakow 1999) prove that there is a difference in the synchronization of CV gestures, which are well synchronized, and that of VC gestures, which are less synchronized. Therefore retroflexes and preceding vowels show more gestural overlap than retroflexes and following vowels.

In the cases where retroflexes influence following vowels or where vowels influence preceding retroflexes (namely in de-retroflexion) this is restricted to retroflex fricatives, affricates, and liquids (see the examples from Gujarati, Chinese, Ponapean and Russian). These segment classes have strong internal cues as described in section 3.1. Furthermore, they have stable articulations without a flapping out gesture as observable in retroflex stops (see discussion in 2.2.4.1), which leads to less reduced CV cues than for stops. These factors can explain why retroflex fricatives, affricates, and liquids but not stops or flaps show perceptual influence on following vowels.

Considering the targets of vowel changing processes, it is mainly the high front vowel or the class of front vowels that is changed, in line with the articulatory incompatibility of these vowels with retroflexes. Lowering in (35b) is the only process illustrated above that occurs also with high back vowels, as discussed above (e.g. in Kayardild, Margany, Gunya, and Tamil). In section 6.3.3 below I will propose formal accounts for the processes avoiding retroflex – front vowel sequences with one example of each process.

4.3.4 Exception: The *ruki*-rule in Sanskrit

The morphophonemic process of retroflexing /s/ after the vowels /u/ and /i/ and after the consonants /k/ and /r/ in Sanskrit (Whitney 1889: 61f.), spelled out in rule-format in (42), is a recurrent topic in phonological descriptions.

(42) s → ʂ / r, u, k, i _

This process is often referred to as the *ruki*-rule and it involves four contexts which seems to make up an unnatural class as they include both back and front vowels, contradicting the rule for deretroflexion in a front vowel context given in (1c). Via the *ruki*-rule the retroflex fricative [ʂ] was introduced into Sanskrit from the proto-Indo-European alveolar fricative /s/.[30] Other retroflex segments in Sanskrit subsequently emerged from assimilation, see section 4.6 below. Examples of the *ruki* rule are given in (43a) with the locative plural suffix /-su/ (Whitney 1889, Flemming 1997). In other environments, this suffix occurs with an alveolar fricative, see (43b).

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[30] The retroflex fricative entered Sanskrit also via a change from Indo-European *k before a /t̪/. This separate development will be ignored here since it is a process that does not occur cross-linguistically and seems to lack a phonetic grounding. For a detailed discussion of this change see Hall (1997b: 213f.).

(43) (a) [svasɻʂu] ‘sister’ (b) [ɟaːsu] ‘progeny’
[çat̪ɽuʂu] ‘enemy’ [apsu] ‘water’
[vaːkʂu] ‘voice’
[agn̪iʂu] ‘fire’

According to Whitney (1889: 61f.), a following [ɽ][31] prevents the retroflexion of /s/. Thus forms like [usɽa] or [t̪isɽas] do not surface as [uʂɽa] and [t̪iʂɽas], as though they satisfy the conditions of the *ruki*-rule.[32] A dissimilation process like this occurs in other languages, too, cf. section 4.6 below.

The [i] context seems unusual as trigger of the *ruki*-rule since retroflexes are expected to avoid front vowels, recall section 4.3 and the articulatory explanation for it in section 2.5. The other three segments triggering the *ruki*-rule are phonetically motivated, however, as discussed below. Several explanations have been put forward for the unusual set of contexts in which the change from an alveolar to a retroflex fricative occurs. Whitney (1889: 61f.) himself proposes an articulatory explanation for its four contexts: retroflexion after a retroflex rhotic is clearly an assimilatory process, and the contexts /k/, /i/ and /u/ share a retracted tongue position which causes the tip of the tongue “to reach the roof of the mouth more easily at a point further back than the dental one” (ibid.). But as Vennemann (1974: 93) points out, it does not follow from the retracting influence of /i/, /u/, and /k/ that the outcome should be retroflex instead of for instance palato-alveolar.

A widespread assumption concerning the development of the *ruki*-rule is that it occurred historically in two stages, with the retroflex as final outcome and a different segment as intermediate output. Misra (1967: 28ff.), Mayrhofer (1989) and Hall (1997b) propose that Proto-Indo-European *s developed to a palato-alveolar fricative [ʃ] in Indo-Iranian in the *ruki* context, and then, via a general rule, to the retroflex in Sanskrit. The two stages of this diachronic process are given in (44).

(44) (a) *s (Indo-European) → ʃ / ɽ, u, k, i _ (Indo-Iranian)
(b) *ʃ (Indo-Iranian) → ʂ (Sanskrit)

Hall proposes that evidence for such an intermediate stage can be found in the fact that the same change (44a) occurred in Avestan, Old Persian and Baltic, where the alveolar remains palato-alveolar, and in Slavonic, where it further changed into a velar [x] (Allen 1951, 1954, Andersen 1968). The change in (44b) is context free, and motivated by Hall as a change towards an unmarked sibilant inventory. The output of (43a), /ʃ/, became phonemic, which caused the two-way sibilant place contrast /s, ç/ in Indo-European to change to /s, ç, ʃ/. Hall shows that this three-way place contrast does not occur in any other language of the world because of the large similarity between /ç, ʃ/, and therefore a further change (43b) was triggered, see the representation of the development in (45).

31 This transcription is mine, based on descriptions in Whitney.
32 Another exception, though not systematic, is the occurrence of a retroflex fricative somewhere after the alveolar fricative, e.g. [si**s**akʂi] (Whitney 1889: 62). In such cases, the *ruki*-rule sometimes does not apply.

(45) *stage 1* → *stage 2* → *stage 3*
/s, ɕ/ → /s, ɕ, ʃ/ → /s, ɕ, ʂ/

Hall's proposal is based on the assumption that the Sanskrit sound represented as 'ś' and described as 'post-alveolar laminal fricative' is the alveolo-palatal [ɕ]. Usually, however, it is interpreted as the palato-alveolar [ʃ], as by Whitney (1889) and Allen (1953). If the palato-alveolar is taken as the Sanskrit post-alveolar fricative, then the outcome of the *ruki*-rule would collapse with this already existing class:

(46) *stage 1* → *stage 2* → *stage 3*
/s, ʃ / → /s, ʃ/ → ? /s, ɕ, ʂ/

From the second stage in this development there is no obvious way to derive the inventory assumed for stage 3. This supports the assumption made by Hall that the Sanskrit laminal post-alveolar is the alveolo-palatal [ɕ], which will be followed here. Hall's proposal, however, does not provide an answer to the question why all four contexts of the *ruki* rule caused exactly the same output, namely a palato-alveolar [ʃ].

Another proposal, going back to Morgenstierne (1929) and applied by Allen (1951: 941), Vennemann (1974), Gnanadesikan (1993: 47), and Flemming (1997), suggests that /s/ assimilated to the four contexts, resulting in different assimilation outputs at an intermediate stage, or several intermediate stages, as Morgenstierne (1929: 2000) proposes. These outputs collapsed at a later stage to the retroflex category, see the development depicted in (47).[33]

(47) *stage 1* → *stage 2* → *stage 3*
/s/ → [s, ^{ɽ}s, ^{u}s, ^{k}s, ^{i}s] → /s, ʂ/

The symbols ^{ɽ}*s,* ^{u}*s,* ^{k}*s,* and ^{i}*s* are used here to indicate the four allophones of the *ruki* assimilation (in line with Vennemann's transcription), and *s* as the allophone occurring in other environments. Allen (1951: 941, 1954: 564) assumes that the outputs of the second stage could have looked like [ʂ, x^w, x, ç], respectively. Gnanadesikan (1993: 47, footnote 22) proposes only three different outputs. According to her, /ɽ/ could have triggered a retroflex fricative, /u/ and /k/ a velar one, and /i/ an alveolo-palatal one. Flemming (1997) suggests also three differing outputs at stage 2, though they differ slightly from Gnanadesikan's. Flemming's outputs are [ʂ, s^w, ʃ, ʃ], respectively. The three proposals are summarized in table 4.2 on the next page.

The exact output of the distinct assimilation processes is obviously not clearly predictable because of lack of supporting evidence. The preceding retroflex can be assumed to have a retroflexing influence on the fricative; cross-linguistic evidence plus a phonetic motivation for this kind of process were presented in section 4.1.

[33] This representation neglects the additional posterior fricatives that occur in Indo-European and Sanskrit given in (45) and (46), as they are irrelevant for the line of reasoning.

Table 4.2 Comparison of different proposals for the output of /s/-assimilation in proto-Indo-European.

	Allen (1951, 1954)	Gnanadesikan (1993)	Flemming (1997)
ɽ _	ʂ	ʂ	ʂ
u _	xʷ	x	sʷ
k _	x	x	ʃ
i _	ç	ɕ	ʃ

The second context, the back vowel /u/, can also cause retroflexion, recall section 4.2 above, though Flemming's assumption of an intermediate stage of a rounded alveolar seems also likely, as it would involve only a change in secondary articulation with a similar acoustic result. Rounding in a back vowel context is also predicted by Allen. For the *k* and *i* context, however, a retroflex output is very unlikely. Retraction of *s* in the context of *k* rather leads to a palato-alveolar [ʃ], or, if place-assimilation takes place, to a velar [x]. The alveolo-palatal [ɕ] is not a possible output of this process, since it is already present in the Sanskrit sibilant inventory. The high front vowel /i/ causes palatalization of a front coronal sibilant which can result in a more posterior place of articulation as in the palato-alveolar [ʃ], see a similar development of palatalization in Basque (Iverson & Oñderra 1985). A summary of these predictions is given in table 4.3.

Table 4.3 Alternative proposal for the output of /s/-assimilation in proto-Indo-European.

input	output
ɽ _	ʂ
u _	ʂ/sʷ
k _	ʃ/x
i _	ʃ

Based on these assumptions, minimally two (for instance [ʂ, ʃ]) to maximally four ([ʂ, sʷ, x, ʃ]) different outputs of *ruki*-assimilation can be postulated.

All assimilatory outputs (those by Allen, Gnanadesikan, Flemming, and my own) have in common that they are acoustically very similar to each other: they all have lowered high frequencies, as pointed out already by Vennemann (1974: 93),[34] though they are acoustically very distinct from /s/. The perceptual similarity of these outputs led to a collapse of all two to four allophones into one category which contrasts with the original category of the alveolar fricative. A merger of acoustically similar allophones is a common diachronic process. In Norwegian, for example, the palato-alveolar [ʃ], an assimilation product from historical /sj/ and

[34] For a discussion on the acoustic similarity of retroflex, rounded fricatives, and palato-alveolar see e.g. Hamann (2002b). Note also that the outputs of the *ruki*-rule assumed by Flemming are particularly designed to be acoustically as close as possible.

/skV/ (Kristoffersen 2000: 23), merged with the output of the retroflexion rule, [ʂ], to one category [ʂ], so *skje* ‘spoon’ is realized nowadays as [ʂeː].[35]

The merger of the four allophones in Sanskrit, however, does not explain why the resulting category is retroflex rather than palato-alveolar, velar or alveolo-palatal. The retroflex category seems arbitrary, as the same process of assimilation in *ruki* context and merger of outputs lead to a different category in other Indo-Iranian languages: in Avestan, Old Persian, and Baltic it resulted in a palato-alveolar fricative, and in Slavic in a velar one. Allen (1954: 564) proposes that the different resulting categories in these languages might be due to already existing processes and categories: in Sanskrit, retroflexion was an established process in connection with liquids, thus the retroflex was a likely category to emerge. Avestan had no retroflex segments or allophones, thus a retroflex is not expected to be the endresult of this development. Allen proposes that the existing palatalization and labiovelarization processes would favour either [ç] or [x^w]. For Slavonic, the already existing opposition of palatalized and velarized articulations promoted the emergence of [ç]/[x] (Allen 1954: 565).

Another instance of fricative merger, which also seems to be motivated by already existing categories occurred in Old High German, according to Vennemann (1974: 94). Here, the allophones of /s/ after /r/ (which might have been a retroflex allophone, analogous to the processes described in section 4.1), and before /w, b, p, m/, i.e. both [^{r}s, s^w], merged with the existing class [ʃ], for instance in the words *bars* ‘bass’, *swert* ‘sword’, *spil* ‘game’, and *smal* ‘small’ (Penzl 1969: 80).

The *ruki*-rule was included in this chapter on phonetically-grounded processes involving retroflexes despite the fact that at first glance this process seems to have an unnatural context with retroflexion occuring after both back and front vowels. At closer investigation it became clear that this diachronic process took place in several stages, each of which with a natural context and a phonetic motivation.

4.4 Retroflexion of vowels

This section deals with the rule of vowel retroflexion illustrated in (1d). Ball & Rahilly (1999: 125) point out that in many languages post-vocalic rhotics can be realized by pronouncing part or all of the vowels with a tongue tip raising or backwards bending instead of a rhotic gesture. The resulting vowels are called r-coloured, retroflexed, or rhotacized, recall the description of retroflex vowels in section 2.2.4.7. Vowel retroflexion is not only caused by rhotics but can also occur before a non-rhotic retroflex consonant, often in combination with a drop of the retroflex. Section 4.4.1 will present examples of vowel retroflexion in retroflex contexts, and section 4.4.2 gives a phonetic explanation for this process.

[35] A further merger can be observed in present day Norwegian, where the phoneme classes [ɕ] and [ʂ] collapse in favour of the retroflex, cf. Papazian (1994) and Dommelen (2001).

4.4.1 Examples

Several Dravidian languages show retroflexion and backing of vowels in pre-retroflex position (Zvelebil 1970: 38). Badaga (Emeneau 1939: 44) even has two types of retroflex vowels, half and fully retroflexed. Examples of this are given in (48) using Emeneau's transcription.

(48)	*Plain vowel*		*half retroflexed*		*fully retroflexed*	
	kae	'unripe fruit'	áé	'tiger's den'	käë	'weeds'
	kombu	'horn'	kómbile	'I did not have (her) as wife'	köë	'carcass'
	be·	'mouth	bé·	'bangle'	bë·	'crops'

Zvelebil gives an example of Badaga vowel retroflexion, which was caused by a retroflex rhotic that was later lost, as comparisons with other Dravidian languages illustrate. Thus 'ass' is [ka˞te] in Badaga, where it contrasts with [kate], 'I learned', whereas in Kota 'ass' is realized as [kaɻʈ]. The retroflexion of vowels in Badaga seems to show some incompatibility with fronted tongue articulations, a process typical of retroflexes as we saw already in section 4.3. Phonetically the half and fully retroflexed /i/ and /e/ are backed. Emeneau (1939) mentions that in the fully-retroflexed phonemes "the elevation of the tongue to mid and high position [is] as far back in the oral cavity as possible, in the half-retroflexed phonemes [it is] advanced almost to the mixed position" (p. 44). The fully retroflexed short /i/ does not occur in Emeneau's data, which he took to be an accidental gap. This gap, however, might be an indication that a fully retroflex short /i/ does not exist in Badaga, due to the large articulatory distance between the retroflex and the front vowel gesture as described above. The existence of a fully retroflexed long high front vowel, e.g. *kï·e* 'down', is no counterevidence to this claim, as the long vowel allows a transition from a front high tongue position to a backed one. Further work on the Badaga vowel system has to be conducted to confirm or falsify this hypothesis.

Koḍagu is another South-Dravidian language in which vowels are retroflexed by a following rhotic, which then gets deleted: the future base /tir-p-/ 'I shall finish' is realized as [tɯ˞p], again with retraction of the vowel (Zvelebil 1970: 38). In Tamil, all retroflex consonants trigger retroflexion of the vowels that precede them (Christdas 1988: 181).

The dialects of British English spoken in West Somerset and North-east Devon have an interesting process involving the retroflex rhotic, a segment typical for this area, followed by a high front vowel [i] or [ɛ]. Besides lowering and centralizing of the vowels to [ə], the rhotic is realized as retroflexion of the vowel. The word *red*, for example, is pronounced as [ə˞ːɖ] in these dialects, and pretty as [pə˞ːɖɪ] (Wakelin 1972: 99).

Australian languages show many processes of vowel retroflexion before retroflex consonants. In Bunuba, according to Rumsey (2000), all vowels followed by /r/ "take on an r-coloration" (p. 44). In some Bunuba words with *g* or *b* followed by /ir/, the /i/ merges completely with the following /r/, e.g. *biray* 'come out' surfaces as [bɽe]. The result sounds like a consonant cluster, according to Rumsey. This process of high front vowel deletion can be taken as further evidence for the dislike of retroflexes and high front vowels, recall section 4.3.[36]

Morphy (1983: 20) observes that in the Djapu dialect of Yolngu, another Australian language spoken in Arnhem Land, all vowels have a slight degree of retroflexion before retroflex consonants. The vowels in the Australian language Yukulta show the same process, according to Keen (1983). In Margany and Gunya, only the low vowel /a/ is retroflexed before a retroflex consonant (Breen 1981), see /ŋanʲbaɖ/ [ŋanʲbaˀɖ] 'sweat'.[37]

While it is usually the preceding vowel so affected, in languages such as Marrithiyel the following vowel is retroflexed. Pitta-Pitta (Australian) is a case where vowels are retroflexed both when preceding and following a retroflex consonant. The retroflexion is apparently weaker in the following vowels (Blake & Breen 1971). And in Bengali, /i/ is said to be somewhat retroflex after /ʈ/, /ɖ/, /lɖ/, and /lʈ/ (Ferguson 1960).

4.4.2 Phonetic grounding

Vowel retroflexion can easily be accounted for as a gestural overlap of the vowel gesture and the retroflexion of the tongue tip: the tongue tip is curled in already when the vowel is still articulated. This overlap of gestures is possible since vowels do not involve the tongue tip in their articulation. If the retroflex apical gesture is not synchronized with the beginning or end of the vowel gesture, it influences the vowel next to it. Especially retroflex approximants, which have no closure and thus no definite point which the retroflex tongue tip gesture can be synchronized with, make retroflexion of a neighbouring vowel very likely. The examples in 4.5.1 show that high front vowels undergo lowering and/or retraction before they are retroflexed. This is due to the dislike of the high tongue middle plus fronted tongue back with the lowered tongue middle and the retracted tongue back of retroflexes.

The gestural overlap occurring in retroflexed vowels is depicted in figure 4.5 on the next page, where the left graphic illustrates non-overlap, and the right total overlap (retroflexion of the vowel).

Vowel retroflexion adds a cue to facilitate the perception of the retroflex consonant, without diminishing the vowel cues as the processes of vowel lowering or retraction. The gestural overlap that occurs in vowel retroflexion can result in a lengthening of the vowel gesture as observed in the Australian language Kayardild (Hamilton 1996: 45, Evans 1985: 504), in order to prolong the cues for the vowel.

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36 The Bunuban example illustrates the difficulty to distinguish between a retroflexed vowel and a retroflex approximant in vowel context. A similar problem is observable in Mayali, a Gunwinggun language spoken in Arnhem Land and Croker Island. According to Evans (1995: 740), Mayali has a process of "syllable-retroflexion" manifested in different ways: the word for 'death adder', for example, can be pronounced as [beɻk], [bɻek], [beɻek], or [bek]. These realizations might be instances of approximant insertion and/or vowel retroflexion, a point to be clarified in future studies.

37 Breen (1981: 289) uses a subscript dot under the /a/ to indicate the retroflexion of this vowel, just as he uses the alveolar with subscript dot for the retroflex series.

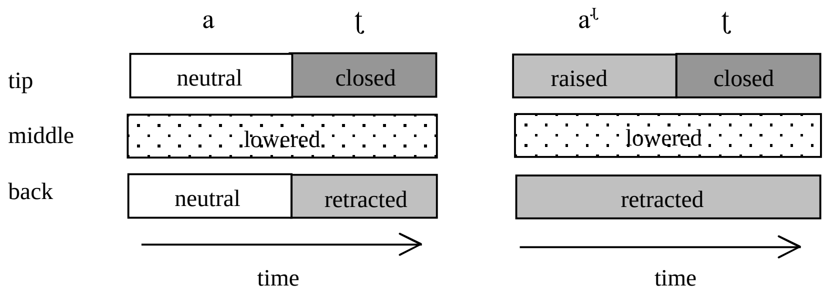

Figure 4.5 Low vowel – retroflex sequences with synchronized gestures (left) and with gestural overlap (right). The three tiers indicate the three tongue parts tip, middle, and back. The tongue blade is not included, since it is not relevant for the depiction of this process. Neutral position of the tongue parts is depicted with white boxes, a positive degree of constriction i.e. raising of the articulator with a grey box (dark grey standing for full closure), and negative constriction i.e. lowering of the articulator with a dotted box.

Retroflexion of a vowel sometimes leads to a deletion of the retroflex consonant triggering it, as in the case of Badaga or the South-Western dialects of Britain, which can be explained by a total overlap of vowel and retroflexion gesture. This process occurs only for retroflex approximants, since approximants do not require a full closure and thus the retroflexion gesture can totally blend with the vowel gesture.

The descriptions above showed that vowel retroflexion often co-occurs with vowel retraction (as described in 4.3.2.1), a further indication of the retroflex gesture being articulated already during the vowel, as a lower tongue position facilitates the retroflexion of the tongue tip.

The more frequent retroflexion of vowels in a position preceding retroflex segments compared to those following retroflexes has also an articulatory explanation: the tongue tip can curl inwards already during the articulation of the vowel (anticipatory gesture), since vowel and retroflex are articulated with different parts of the tongue. Thus an overlap of both gestures is possible. Gestural overlap is also possible in the other direction, and results in retroflexion of a following vowel (as was shown for Marrithiyel, Pitta-Pitta, and Bengali). But instead of an anticipatory gesture which saves articulatory time, the retroflex gesture is held longer than necessary in this case and thus influences the vowel. Retroflexion of following vowels is probably perceptually motivated by an enhancement of the retroflex cues only, whereas retroflexion of the preceding vowel is perceptually and articulatorily motivated.

4.5 Phonotactics of retroflex segments

This section is concerned with restrictions on the phonotactics of retroflexes. The occurrence of retroflexes within a syllable and a prosodic word is cross-linguistically asymmetrical: word-finally and post-vocalically they occur more often than in word-initial position and post-consonantally, see (1e). This asymmetry was the topic of an extensive study by Steriade (1995, 2001a), whose phonetic explanation will be largely followed here. Steriade's analysis is described in detail in section 5.3.3.

The following subsection 4.5.1 gives some examples of this asymmetrical behaviour. Possible phonetic accounts are discussed in subsection 4.5.2.

4.5.1 Examples

This section discusses two language families: the Australian languages, which mostly have two apicals and two laminals and show a number of interesting restrictions on the occurrence of retroflexes, and the Indo-Aryan languages, with smaller coronal inventories.

Most Australian languages have no retroflex segment word-initially, which leads to a neutralization of the contrast between apical alveolar[38] and retroflex in word-initial position as described by researchers such as Evans (1995: 727), Hamilton (1993: 134), and Gnanadesikan (1993: 35). Bunuba (Rumsey 2000) is such a language. Word-medially, Bunuba contrasts both apicals, see (49a) (the sounds in question are boldfaced), whereas word-initially only apical alveolars occur, see (49b). If a subsequent syllable contains [ɖ, ɳ, ɭ], the word-initial apical is realized as retroflex, see (49c), which is an instance of long-distance retroflexion, to be discussed in section 4.6.2.[39]

(49)	(a)	bi**ɖ**i	'thigh'	wi**d**igi	'stick insect'
		ga**ɭ**u	'penis'	ga**l**u	'road'
		dʒi**ɽ**igi	'bird' (gen.)	dʒi**r**ingin	'owlet nightjar'
	(b)	**l**aɲi	'freshwater eel'		
		dumuru	'chest'		
	(c)	**ɳ**aɖʌ	'short'		
		ɖuɭu	'heart'		

Further Australian languages with the same restrictions on retroflexes word-initally and word-finally are Andiljaugwa (Dixon 1970), Kalkatungu (Hamilton 1996), Kitja (Dixon 1980), Ndjébbana (McKay 2000)[40], Ngiyambaa (Donaldson 1980), Thargan (Dixon 1980), Watjarri (Douglas 1981), and the closely-related Margany and Gunya (Breen 1981). Only 3 of the 22 languages Dixon (1980) investigates show an apical contrast in word-initial position.

A number of Australian languages is reported to have a retroflex but no apical alveolar in word-initial position. That is, the apical contrast is neutralized in favour

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[38] As defined in chapter 1, 'apical alveolar' is used in this dissertation to denote any kind of front apical articulation, i.e. it includes both alveolar and dental place of articulation.

[39] The rhotic /ɽ/ is the only retroflex segment that does not trigger the retroflexion of word-initial apicals. Recall from the data in (19) that the high front vowels in these examples are retracted before a retroflex.

[40] The retroflex rhotic in Ndjébbana, however, does occur in word-initial position, where it contrasts with the apical alveolar rhotic (McKay 2000: 177).

of the retroflex place of articulation. Hamilton's (1996) database of Australian languages lists Bularnu, Djambarrpuyngu, Gaalpu, Kayardild, Mangarrayi, Marra, Ngalakan, Ngandi, Pintupi, Pitta-Pitta, Ritharrngu, Wardaman, Wambaya, and Walmatjari[41] as such languages. Lardil is a further example of an Australian language with a retroflex as the only apical in word-initial position (Dixon 1970, Gnanadesikan 1994: 128). Sharpe (1972) describes that Alawa, a Maran Australian language spoken in Arnhem land, has a retroflex in word-initial position following a vowel and within a phonological phrase. In the same position following a phrase boundary, the segment is alveolar. This indicates a dependency of the type of articulation on the phrasal position.

For some Australian languages free variation between both apicals is reported. According to Hamilton (1996: 133), Gooniyandi is such a language, where the two word-initial apical series vary freely between alveolar and retroflex articulation when not conditioned by a following apical (50a) (data based on McGregor 1990: 70f.). When the following consonant is apical, the initial apical segment harmonizes to this place of articulation, see (50b). Laminal consonants that follow the retroflex do not cause assimilation of the initial segment to a laminal articulation, see (50c).

(50)	(a)	/duwu/	[duwu ~ ɖuwu]	'cave'
	(b)	/diɽipindi/	[ɖiɽipindi]	'he entered'
		/dili/	[dili]	'flame; light'
	(c)	/laɲgija/	[laɲgija ~ ɭaɲgija]	'midday'

Neutralization occurs also post-consonantally in Gooniyandi, whereas post-vocalically, a contrast between retroflex and apical alveolar is given, see (51).

(51)	/kiliɳi/	[kili**ɳ**i]	'grass'
	/waɖguluna/	[waɖgulu**n**a]	'I bring them'

McKay (2000: 177) mentions that the Ndjébbana neutralized initial apical sometimes appears to be retroflex, thus providing another example of variation. Butcher's (1992) phonetic study shows that free variation occurs in the neutralized position of several Australian languages.

Besides in word-initial position, retroflexes also have the tendency not to occur post-consonantally, see Gooniyandi. A language showing neutralization after consonants but not in initial position is Nunggubuyu (Steriade 1995: 18).

Languages that have an apical contrast only intervocalically and in V_C position are numerous on the Australian continent. The Djapu dialect of Dhuwala-

[41] Walmatjari has been subject of several studies with differing interpretations. According to Gnanadesikan (1993: 49) this language has retroflexes only utterance-initially, but alveolars morpheme-initially and word-initially. Gnanadesikan (1994: 128f.) states that there is free variation between alveolars and retroflexes in syllable-initial positions in Walmatjari, except after /u/, /a/ and other retroflex consonants, where they are solely retroflex. This interpretation is based on Hudson & Richards (1969) who claim that the alveolar/retroflex contrast is "neutralized", and who use the symbols ṭ, ḍ, etc. for their transcription.
Gnanadesikan further proposes that one might interpret the Walmatjari initial apicals as being articulated midway between an alveolar and a retroflex, see discussion in section 4.5.2 below.

Dhuwal (Morphy 1983, Hamilton 1993: 131), for example, has both apicals and laminals post-vocalically in coda position with a following non-coronal. Homorganic coronal clusters are also allowed, for instance [miːɳ.ɖuŋ] 'snail'. These tendencies in Australian phonotactics lead Dixon (1980: 155) to posit restrictions on the occurrence of segments in words of the general shape $C_1VC_2C_3VC_4$: the apical contrast only occurs at C_2 and C_4, i.e. those slots that follow a vowel. Apical contrasts do not generally occur in C_3-position in a heterorganic cluster.

A number of Dravidian and Indo-Aryan languages also disallow retroflexion word-initially. Proto-Dravidian has neither retroflex nor alveolar consonants in word-initial position, i.e. no word begins with [t, l, r, ʈ, ɳ, ɭ, ɽ] (Zvelebil 1970: 77). This behaviour holds for many modern Dravidian languages, such as Iruḷa (Diffloth 1975).[42] Tamil (Christdas 1988), Koḍagu (Ebert 1996), and Toda (Shalev, Ladefoged & Bhaskararao 1993: 101). In the Indo-Aryan language Punjabi, all phonemes are allowed in word-initial position apart from the retroflex liquids [ɭ, ɽ] and the nasal [ɳ]. Punjabi, however, allows [ɭ] and [ɽ] as final members in word-internal three-consonantal clusters such as [lombɽiː] 'fox' and word-final clusters such as [kʈ, nɖ, lʈ, rɖ] (Bhatia 1993: 340).

Interestingly, some Indo-Aryan languages with a twofold apical series but no retroflexes in word-initial position allow both apicals word-initially in loanwords. In Koḍagu (Ebert 1996), for example, retroflex consonants do not occur initially in native words. In loanwords, however, word-initial retroflex consonants are quite frequent: English /t/, for instance, is rendered in Koḍagu as [ʈ]: *teacher* is [ʈiːtʃerɯ] (Ebert 1996: 6).[43] Punjabi (Bhatia 1993) also only allows retroflexes in loanwords, e.g. [ʈraːm] 'tram'. The Dravidian Tamil allows the retroflex fricative [ʂ] initially exceptionally in some proper nouns, all of them recent borrowings from Hindi or Sanskrit.

4.5.2 Phonetic grounding

As we saw in section 4.5.1 above, several Australian languages suspend the contrast between the two apicals in word-initial position and in post-consonantal position. The realization of the apical in these positions varies; some languages choose an apical realization, others a retroflex one, and some allow variation between the two.

From an articulatory point of view, one would expect the apical contrast to neutralize towards the apical alveolar, as the apical alveolar involves a less complex articulation than the retroflex since no displacement of the tongue tip is involved

42 The segment /ʈ/ can occur in a number of items in some Dravidian languages word-initially. Zvelebil (1970: 102) explains the occurrence of /ʈ/ word-initially by four processes: assimilation towards following (but not immediately adjacent) retroflex nasals (to be discussed below in section 4.6.2), metathesis, onomatopoetic forms, and borrowings from non-Dravidian languages.

43 The retroflex phonemes might be chosen as equivalent to English alveolars because the English interdentals /θ/ and /ð/ are represented in Koḍagu by the dentals [t̪] and [d̪], respectively. In order to retain a distinction between the two English coronal series, these phoneme classes are transferred to the two perceptually closest native coronal phonemes (dental and retroflex). A similar shift in coronal categories for the adaptation of English words can be observed in Kannada (Schiffman 1983: 11ff.): *town* [ʈaʊnu] or *end* [ɛɳɖu] versus *thing* [t̪$^{(h)}$ɪŋ] or *thanks* [t̪$^{(h)}$eːŋksu].

(recall the universal articulatory markedness hierarchy under (2) in chapter 1). Steriade (1995) points out that languages with a contrast between apical dental and apical retroflex have two articulations with displaced tongue tip, as the dental involves a fronting of the tongue. In these languages an articulatory neutralization towards the apical alveolar should be expected, according to Steriade. This occurrence of a third articulatory position in neutralization is possible, but is not reported very often. Due to the tendency of language transcribers to classify occurring segments into the phonemically existing apical categories of a language (either dental or retroflex), this deviation may pass unnoticed. It seems unlikely, however, that languages should employ a new categorical articulation instead of one of the already existing ones because of the general tendency to re-use already learned gestures. Further phonetic studies investigating the actual articulation of apical segments in sites of neutralization are necessary to clarify this point.

The articulatory variation and neutralization observed in the phonotactic patterns of retroflexes is only acceptable if the resulting output shows no large perceptual deviation from the input. It was shown in section 3.5 that retroflexes have strong VC transitions, and that their CV transitions are weaker and more similar to those of apical alveolars. Steriade (1993b) used this fact to explain why the neutralization of apical contrast mostly takes place in word-initial and post-consonantal position: the cues distinguishing between apicals are insufficient in these positions that have no VC transitions, recall the markedness hierarchy under (4) in chapter 1. The less distinct CV cues of apicals can also explain why a language such as Proto-Dravidian has no apical in initial position at all. Furthermore, the lesser saliency implies that a language should not employ a contrast between retroflex and apical alveolar in postconsonantal position without having this contrast in postvocalic position. This was attested by the data above: no language could be found that contrasts alveolar and retroflex apicals in initial or postconsonantal position only.

Flemming (2002) argues that the CV transitional cues and the VOT cues of retroflexes are more contrastive with those of laminals than the apical alveolar or dental cues are. Following from this, Flemming assumes the neutralized apical is retroflex, in order to preserve the contrast with the laminal series. This assumption sounds reasonable but is not confirmed by the data: the examples given in 4.5.1 show no preference for retroflexion in neutralized positions.

In sum, the asymmetrical behaviour of retroflex cues can account for the phonotactic behaviour of this class. The realization of the neutralized category, however, seems to be language-specific. Constraint rankings in an OT framework, which can account for the cross-linguistic phonotactic differences are proposed in section 6.3.6.

4.6 Assimilation of retroflexion

Languages with retroflex segments commonly show assimilation processes involving this specific articulatory class, see (1f). Two kinds of assimilation can be observed, one of adjacent segments and one of segments which are separated by intervening material, see rule (1f), repeated here as (52).

(52)	(a)	ʈt	→	ʈʈ	or	tʈ	→	ʈʈ
	(b)	ʈVt	→	ʈVʈ	or	tVʈ	→	ʈVʈ

Examples of local assimilation processes like (52a) are presented in section 4.6.1, examples for long-distance retroflexion (52b) in 4.6.2. A phonetic account for both is proposed in 4.6.3.

Assimilation is topically related to dissimilation processes. Dissimilation of retroflexes occurred for example with Proto-Dravidian consonant sequences such */ɳʈ/, which occur as [nɖ] in several modern Dravidian languages.[44] Another example for dissimilation is the infinitive marker –/ɳaː/ of Punjabi which has a variant [naː] after retroflex segments, cf. /jaːɳ+ɳaː/ 'to know' [jaːɳnaː] (Bhatia 1993). Dissimilation processes are probably due to the need for increased perceptual distinction. These processes are not further treated in this dissertation.

4.6.1 Local assimilation

Let us first look at examples in which retroflexes affect following segments. Retroflex segments in Swedish and Norwegian assimilate following dentals into retroflexes. Examples from Swedish (from Eliasson 1986: 280) are given in (53).[45]

(53)	/haʈs/	[haʈʂ]	*harts*	'resin'
	/ɛɳst/	[æɳʂʈ]	*Ernst*	(name)
	/væɖslig/	[væːɖʂɭig]	*världslig*	'worldly'
	/kvaʈssekel/	[kvaʈʂʂeːkəl]	*kvartssekel*	'quarter-century'

This assimilation is iterative, that is, dentals following the assimilated retroflex are also retroflexed, as all but the first example in (53) illustrate.

Norwegian assimilation of retroflexes has an equivalent in Swedish. An interesting phenomenon concerning Norwegian retroflex assimilation is the formation of the patronymic form, by the addition of the suffix *-sen* /-sn̩/ to a name. According to Kristoffersen (2000: 318), three different conditions for this process have to be distinguished. If the name ends in an /r/, then the two coronals in the suffix are retroflexed and the *r* is deleted: *Persen* [peː.ʂɳ̩]. If the name ends in a retroflex, *Gjert* [jæʈ], then the initial segment of the suffix will be realized as retroflex. The nasal, however, remains dental: [jæʈ.ʂn̩], not *[jæʈ.ʂɳ̩]. If the name ends in an assimilated retroflex, *Morten* /moʈn/ [mɔ.ʈɳ̩],[46] where the retroflexion of

[44] According to Zvelebil (1970: 169), these languages are Kolami, Naikṛi, Parji, Gondi, Konda, Pengo, Kurukh, Malto, Brahui, and Kuvi.

[45] Retroflexion in Swedish does not assimilate from lateral to non-lateral, compare *pärltråd* [pæːɭtroːd] 'string of pearls' to *pärllist* [pæːɭɭist] 'pearl molding' (Eliasson 1986: 280). No explanation for this exception seems to be available.

[46] Kristoffersen (ibid.) represents the surface structure of *Morten* with a geminate retroflex stop, in order to encode the shortness of the vowel. A different way of encoding vowel length is to assume an underlying length specification of Norwegian vowels (see discussion in Fretheim 1983), which makes Kristoffersen's move unnecessary.

the final segment originates from the previous retroflex, further spreading is blocked: the output form is [mɔ.ʈɳ̩.sn̩], not *[mɔ.ʈɳ̩.ʂn̩] or *[mɔ.ʈɳ̩.ʂɳ̩]. A way of summarizing these three conditions is to assume a restriction on the number of retroflex consonants for this process: no more than two retroflex segments are allowed on the surface.

In both Norwegian and Swedish, assimilation of a dental to a retroflex is progressive. A similar rule can be found in some Dravidian and Indo-Aryan languages. In Kannada (or Kanarese), a Dravidian language spoken in the Karnataka state of South India, sequences of a retroflex (lateral, stop or nasal) and a non-retroflex coronal usually show progressive assimilation of the non-retroflex (Schiffman 1983: 8, 16). The examples in (54) illustrate this point.[47]

(54)	/heːɭ-al-ila/	[heːɭɭɪla]	tell-inf-neg	'didn't say'
	/koɭ-d-e/	[koɭɖə]	obtain-past-1s	'I obtained'
	/tɔʈilu/	[tɔʈɭu]		'cradle'
	/kaːɳ-d-e/	[kaːɳɖə]	see-past-1s	'I saw'

In rapid speech, Kannada also shows progressive assimilation of retroflexion with other segments (Sridhar 1990: 303). Furthermore, in colloquial Kannada a voiced retroflex stop is sometimes inserted between a coronal lateral or nasal and [r], see the examples in (55) (Schiffman 1983).

(55)	(a)	/ellaru/	[ɛlɖru] ~ [ɛldru]	'all people'
	(b)	/eːɭroː/	[eːɭɖroː]	'get up!'
		/kaɭːaru/	[kaɭɖru]	'thieves'

Sridhar (1990: 311) claims that if a dental precedes the inserted stop, this stop can be either dental or retroflex, see (55a). If the preceding coronal is retroflex, however, as in the case of (55b), the inserted stop is always retroflex. This follows the general tendency of progressive assimilation of retroflexion. Further assimilation of the /r/ is prevented as Kannada has no retroflex rhotic.

In many Dravidian languages an alternation between a retroflex lateral and a retroflex stop can be observed.[48] According to Zvelebil (1070: 102), this alternation originates historically in a progressive assimilation of /ɭ/ + /t/ > /ɭʈ/ and a subsequent deletion of the lateral. Furthermore, the geminate [ɖː] in Telugu and Kannada probably arose from the progressive assimilation of a voiced dental suffix *–d* to a preceding root-final /ʈ/, i.e. /ʈ/ + /d̪/ > /ɖɖ/. Examples are Telugu [aɖːu] and Kannada [aɖːi] 'to obstruct' from Proto-Dravidian *aʈ- (Zvelebil 1970: 104).

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[47] The retroflex and the non-retroflex in Kannada are often only adjacent after deletion of an intermediate vowel. This process of vowel deletion and another one of vowel reduction, also observable in the data in (55) are not discussed here.

[48] In South-Dravidian, there is a widespread alternation between [ʈ] and [ɭ], as Zvelebil (p. 101f.) describes, with [ɭ] probably as the original sound: Literary Tamil /amːaviɭam/ 'with mother' is realized as [amːaviʈam] in Madurai Tamil. There is also an alternation with [ɳ] in certain items: Tamil [taɳ] 'coolness, cool' vs. [taɭi] 'coolness', Malayalam [taɳ] 'cold', Kannada [taɳ] 'coldness, cold'. Again, [ɭ] is presumably the underlying phoneme, and Zvelebil (p. 102) proposes the development */ɭ/ > [ɭ] / [ɳ] / [ʈ].

Diachronically retroflex stops were introduced into Sanskrit by progressive assimilation of dentals to the already existing retroflex fricatives (recall section 4.3.4 on the diachronic development of the fricative).[49] Thus, the following development occurs: *ʂt > ʂʈ and *ʐd > ʐɖ (Bhat 1973: 33). Examples are given in (56) (from Misra 1967: 68f.); they show that the triggering retroflex fricative was deleted at a later stage, when the retroflex stops had become phonemic.

(56)	*Sanskrit*		*pre-Sanskrit*	*gloss*
	n̪iːɖa	<	*n̪iʂda	‘nest’
	miːɖʰa	<	*miʂd̪ʰa	‘reward’
	voːɖʰum	<	*vaʂd̪ʰum	‘to carry’
	leːɖʰi	<	*laʂd̪ʰi	‘licks’

Another example of the assimilation of retroflexion comes from south-western British dialects that have a retroflex [ɻ] (recall description in section 4.1). In these dialects, an assimilation of the following alveolar to this retroflex segment occurs, so ‘*readers*’ is realized as [ɻiːdəɻʐ] (Ball & Rahilly 1999: 56). According to Wakelin (1972: 99), the rhotic is deleted in such cases and surfaces as vowel retroflexion (cf. section 4.4): *tears* (verb) [tɛ˞ːʐ] and *shirt* [ʃə˞ːʈ]. Besides progressive assimilation these dialects also have regressive assimilation, e.g. *tree* [ʈɻiː] or *straw* [ʂʈɻɔː] (ibid.).

Let us look at examples of processes where retroflexes cause assimilation of the *preceding* segments. Modern Telugu has regressive assimilation after vowel deletion, see the examples in (57) (based on Gilbert 1992).

(57)	/paːt̪a+ʈeːbilu/	[paːʈʈeːbilu]	‘old table’
	/ad̪i+ɖabbaː/	[aɖɖabbaː]	‘that is a can’

In Sanskrit, dentals also undergo regressive assimilation to retroflexes, see (58a) (Whitney 1889: 66f., Allen 1962: 83ff.).

(58)	(a)	/t̪at̪+ɖaukat̪eː/	[t̪aʈɖaukat̪eː]	‘it approaches’
		/t̪aːn̪+ɖimb̤aːn̪/	[t̪aːɳɖimb̤aːn̪]	‘those infants’
		/paːt̪as̪+ʈalat̪i/	[paːt̪aʂʈalat̪i]	‘the foot is disturbed’
	(b)	/t̪aːn̪+ɟan̪aːn̪/	[t̪aːɲɟan̪aːn̪]	‘those people’
		/eːt̪at̪+t̠ɕʰat̪t̪ram/	[eːt̪at̠t̠ɕʰat̪t̪ram]	‘this umbrella’
		/t̪at̪as̪+t̠ɕa/	[t̪at̪aɕt̠ɕa]	‘and then’

The regressive assimilation process in Sanskrit applies also to palatals, see (58b). A dental, however, does not trigger assimilation of a preceding coronal, e.g. /ʂaʈsu/.[50]

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[49] Another source for retroflex segments in Sanskrit were borrowings from Dravidian, see Burrow (1955) and Masica (1991) for discussion and examples. Masica (1991: 157f.) further mentions the introduction of non-sibilant retroflexes via the retroflex rhotic and its syllabic counterpart, which leads to the question of how these segments were introduced into the language. For a possible answer, see section 4.1 above, where it was proposed that rhotic approximants can emerge easily as alternants of non-retroflex coronal rhotics.

[50] On the contrary, one case of progressive assimilation of dental to following retroflex occurs, namely when the retroflex is the fricative [ʂ] (Whitney 1889: 67f.), e.g. /dviʂtas/ [dviʂʈas] or /dveːʂtum/ [dveːʂʈum].

Regressive assimilation is also present in Vietnamese, where retroflex /ʈ/ and /ɳ/ occur after a vowel (word-final) only if the following word has an initial retroflex affricate (Bhat 1973: 45).

Indo-Aryan Punjabi (Bhatia 1993: 347) shows the reverse process of the usually observed one: a retroflex is assimilated to the following nasal dental. Punjabi regressive assimilation of a stem-final retroflex to the following dental nasal of the present-I suffix -/naː/ is exemplified in (59).

(59)	maɳ	'to agree'	+ naː	[manːaː]
	d̠ʒaːɳ	'to know'	+ naː	[d̠ʒaːnːaː]

Besides assimilation to retroflex segments, one can also find assimilation of retroflexes towards other places of articulation. Colloquial Tamil (Zvelebil 1970: 103), for example, has a process whereby retroflexes are assimilated to following non-coronals, namely palatals, velars, and labials. Examples of this process are given in (60).

(60)	*Literary Tamil*	*Colloquial Tamil*	*gloss*
	[uʈkaːrnteːn]	[okkaːndeːn]	'I sat'
	[kaʈci]	[kacci]	'party'
	[keːʈpeːn]	[keːppeːn]	'I shall hear'

This process is not restricted to retroflexes, other coronals such as alveolar /t/ for example assimilate as well.

4.6.2 Non-local assimilation

In a small number of languages retroflex sounds can cause retroflexion of non-adjacent coronal segments. Examples of such long-distance retroflexion occur for instance in Sanskrit, South-Dravidian, and Australian, indicating that it is not a feature specific to one language family or to areal contact.

In Sanskrit *n* is retroflexed when it follows a retroflex continuant [ʂ], or any rhotic. Examples for this so-called *nati* rule are given in (61) with the middle participle –aːn̪a– (Whitney 1889: 65).[51]

(61)	[puraːɳa]	'fill'	+ middle participle
	[t̠ɕakʂaːɳa]	'see'	+ middle participle
	[kʂub^{h}aːɳa]	'quake'	+ middle participle
	[kr̩paːɳa]	'lament'	+ middle participle

However, the *nati* rule is blocked by intervening non-retroflex coronal consonants: [kʂvedaːna], 'hum' + middle participle (ibid.).

In Dravidian, long-distance retroflexion occurs as a diachronic process. The development of initial retroflex stops in some Dravidian languages is due to the spread of retroflexion from a retroflex nasal occurring after but not adjacent to the

[51] N-retroflexion occurs only when the nasal is followed by a vowel, another nasal or a glide, hence the alternation [brahma**n**] vs. [brahma**ɳ**aː] 'Brahman' (Whitney 1889: 65).

initial segment in the same word, and a deletion of the retroflex nasal at a later stage. Thus, Proto-Dravidian *taɳk- ‘to be obtained/ to remain’ is [taɳːuka] in Malayalam or [taɳku] in Tamil, but [ɖakːu] in Telugu (Zvelebil 1970: 102). Presumably this process was blocked by intervening coronal consonants, though this hypothesis requires further testing.

In the Australian language Mpakwithi the retroflex continuant [ɻ][52] causes retroflexion of the vowel which occurs in the preceding syllable, even if consonants occur between these two segments: /gwapɹa/ ‘is eating’ is realized as [^{ŋ}gwa^{ɻ}fɻa] (Evans 1995: 739). In Ritharngu or Ritharungo (Heath 1980), spoken in Eastern Arnhem Land, a retroflex causes retroflexion of a preceding vowel even across a glottal stop: /ɭaʔɭa/ ‘metal axe’ is realized as [ɭa^{ɻ}ʔɭa] (Heath p. 11).

4.6.3 Phonetic grounding

Assimilation processes are articulatorily motivated by a reduction of the different places of articulation of two (adjacent) segments to one place. This reduction is usually the case if the gestures are made with the same articulator, for instance if both are apical. If the articulators differ, as in sequences of labial and apical, for example, one finds overlap of gestures (see the studies of Browman & Goldstein 1989, and many others). The overlap results in a loss of perceptual cues for one gesture and subsequent reduction of this gesture.

The direction of assimilation is usually regressive, i.e. assimilation of a segment to the following occurs. This direction is motivated by the anticipation of the following gesture during the articulation of the present segment. Apicals, however, show a preference for progressive assimilation, as observed by Steriade (1995, 2001). Applied to retroflexes, this means that they cause a change of the following segment into a retroflex, or that a retroflex itself assimilates to a preceding segment. Steriade accounts for this behaviour by the perceptual strong VC cues of retroflexion, which override the less strong CV cues of other segments: spreading proceeds from the segment possessing more salient place cues to the segment with less salient cues. Thus, a retroflex followed by an apical alveolar or dental has strong VC cues, which override the CV cues of the following apical consonant. A retroflex preceded by an apical alveolar, on the other hand, is itself assimilated to the preceding segment, as the VC cues of the apical alveolar are stronger than the CV transitional cues of the retroflex, as Steriade argues.

The implications of this explanation are, however, not always met. In a sequence of retroflex plus non-retroflex apical, the retroflex segment does not generally determine the output of the assimilation. There are cross-linguistically a number of cases where the retroflex is assimilated to the following apical, as in the examples from Punjabi in (59), where the retroflex nasal assimilated to a following dental nasal. Furthermore, retroflexes can cause regressive assimilation of preceding dentals, as testified by the examples in Sanskrit, British English, and Vietnamese.

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[52] This segment is transcribed as [ɹ] by Evans, but is referred to as retroflex continuant at a later point (p. 740).

Sanskrit even has a process of regressive assimilation of a retroflex to a following dental, which is exactly the opposite of Steriade's prediction.

In sum, there are perceptual reasons why retroflexion should spread preferably towards the following segment, but these motives are not as strong in every language as to result in a universal pattern of progressive assimilation for retroflexes. Local assimilation of retroflexion is in principle not restricted to coronals, but whereas an example could be given for the assimilation of a retroflex to a following velar, palatal or labial in colloquial Tamil, I could find no example of a retroflex segment causing an adjacent non-coronal to turn into a retroflex. A phonetic explanation for this gap cannot be provided here.

For non-local assimilations a different account than for local assimilation has to be put forward, since the segments are not adjacent and thus the process can be blocked by intervening segments. An articulatory explanation for the *nati*-rule in Sanskrit was proposed by Whitney (1889: 65), who assumes that once the tip of the tongue is in the retroflex position, it stays there to make the next nasal coronal contact, unless a segment interferes that demands a different tongue front position, such as another coronal. The same assumption of holding the tongue tip gesture is made by Evans (1995) for the long distance retroflexion in the Australian language Mpakwithi: the retroflexion of the tongue tip, which is independent of the rest of the tongue, can be slower than the movements of the rest of the tongue. This explanation is valid only if the intervening segment is non-coronal. Evans' examples do not contain intervening coronals.

Ritharngu as described by Heath has *vowel* retroflexion across the glottal stop only, where the tongue tip can be held in retroflexed position during the intervening segment. The preservation of the tongue tip gesture is thus a reasonable explanation that can account for the data of the Australian, Indo-Aryan, and Dravidian examples. This articulatory explanation can also account for why coronal segments block the effect: they force the tongue tip to assume a different position and thus inhibit a continuation of the assumed gesture. Furthermore, this accounts for the fact that long-distance retroflexion can only apply to coronal consonants or to vowels which can be articulated with an additional tongue retroflexion (recall section 4.4), not to labials or velars.

No restriction on the direction of influence could be observed for long-distance retroflexion: in Sanskrit the retroflex changed segments that occurred after it, in Telugu segments before it.

Long-distance assimilation is observed very infrequently in languages with retroflexes. This could be explained by the fact that long-distance assimilation, if it indeed involves a retroflex gesture that is held over several segments, affects intervening segments, thus the vowels between trigger and target are retroflexed. This is probably not tolerable in most languages.

An analysis for both local and non-local retroflex assimilation is given in section 6.3.6.

4.7 Excursion: Retroflex fricatives in Toda

In section 2.2.6 the large coronal fricative system of Toda was introduced. Toda has voiced and voiceless fricatives. The following discussion, however, is restricted to the voiceless series. Furthermore, only the apical post-alveolar fricative, transcribed here as a retracted alveolar [s̠] (following Sakthivel 1976, 1977), and the subapical palatal fricative, transcribed as [s̡], are of interest. It was illustrated in section 2.2.6 that both segments can be considered retroflex, since the apical post-alveolar is similar to retroflex fricatives in other languages, and the subapical palatal is retroflex under every possible definition of retroflexion. Applying the four retroflex properties as postulated in section 2.3, the subapical palatal satisfies all four. The apical post-alveolar also satisfies all four if we follow Ladefoged & Maddieson's (1986) description of this segmental class. Ladefoged (2001: 153) describes this sound as apical alveolar with secondary velarization. According to this description, this sound class would neither satisfy the property of posteriority nor that of sublingual cavity, and thus not be considered a retroflex, see the discussion in section 2.4.3. In the present section the phonological behaviour of both segmental classes is investigated to see whether both show typical retroflex behaviour as given in (1) of this chapter, or whether the apical post-alveolar does not. The latter case would provide evidence for a phonetically retroflex (assuming Ladefoged & Maddieson's (1986) definition) but phonologically non-retroflex class.

The first indication to look at is *front vowel incompatibility*, because this occurs very often with retroflex classes (cf. section 4.3). Both Toda fricatives /s̠/ and /s̡/ occur after the short and the long high front vowel, see (62a) and (62b), respectively, with short vowels in the left column and long vowels in the right column (Sakthivel 1976: 69ff. and 176ff.).[53]

(62)	(a)	kɪs̠	'to crow'	kiːs̠	'handle (of spoon etc.)'
	(b)	is̡θɑːs̠	'nighttime'	kiːs̡	'Mund of the *Pïːr̡* clan'

The occurrence of the two apical fricatives before the high front vowels seems to be allophonic: the apical post-alveolar /s̠/ occurs only before the short vowel, see (63a), and /s̡/ only before the long vowel, see (63b) (ibid.).[54]

(63)	(a)	nes̠ɪʃkj	'rice'
	(b)	kɔs̡iː	'name of a buffalo'

The examples in (62) and (63) illustrate no particularly retroflex behaviour of the two classes with respect to front vowel incompatability.

The next process that could yield information on the phonologically retroflex status of the apical post-alveolar fricative in Toda is *palatalization*. Sakthivel (1976, 1977) consistently uses the separate symbol of the palatal glide [j] to transcribe both

[53] The first example in (62a) shows vowel lowering of the short /i/ to [ɪ] interconsonantally (Sakthivel 1976: 50), see also the first example under (63a).

[54] The sequence retroflex plus long high front vowel occurs in Toda only word-finally (Sakthivel 1976: 75f.).

the phoneme as well as what others (for instance Emeneau 1984) transcribe as secondary palatalization. I will follow Sakthivel's transcription because I find an incompatibility of retroflexes and secondary palatalization well-supported (as elaborated in 2.5 and 4.3.2.5). The palatal glide occurs only after the apical post-alveolar /s̲/, see the examples in (64) (Sakthivel 1976: 216 and 219), not after the subapical palatal.

(64)	ɯs̲jam	'exactly'
	is̲j	'rat'

Interestingly palatalization occurs after all other subapical palatals in Toda apart from the fricative, see the examples in (65).

(65)	pɪʈ̣jk	'in vain'
	oːɳ̣j	'nail'
	nɪɽ̣j	'Mund of the *Niṛy* clan'
	kɪɭ̣j	'parrot'

As shown in section 2.2.6, the Toda fricatives are the largest coronal series in this language, the subapical stop contrasts only with a dental and an alveolar, and the nasal, rhotic, and lateral only with an alveolar. The occurrence of palatalization with all very retroflex consonants except the very retroflex fricative may indicate that the stop, nasal, trill, and lateral have a lesser degree of retroflexion, and are presumably articulated more like the apical post-alveolar fricatives, which might be due to the smaller stop, nasal, trill, and lateral inventories (cf. section 2.2.6). This suggestion has to be further investigated.

The palatalization processes therefore make a distinction between the palatal subapical fricative, which behaves in this respect like retroflexes in other languages, and the apical post-alveolar fricative, which does not. The sequence palatal glide plus fricative, however, unites the two classes again: the glide occurs neither before the subapical palatal nor before the apical post-alveolar fricative (but it occurs before other coronal fricatives). This is illustrated e.g. by the fact that the genitive marker –*s̲* changes to a [ʃ] if added to a word ending with a palatal glide, see (66) (Sakthivel 1977: 44f.).

	input	*output*	*gloss*
(66)	ɑɖ̣j – s̲	ɑɖ̣jʃ	'in the pot'
	poːj – s̲	poːjʃ	'in the mouth'
	muːd̲ pɔɭ̥j – s̲	muːd̲ pɔɭ̥jʃ	'in three dairies'

Unfortunately, there is no morpheme with an initial –*ʂ̥* that could illustrate a corresponding change of the fricative. The argumentation of an incompatibility of tongue gestures for retroflex and palatal that was applied to account for the non-occurrence of palatalized retroflexes can be used here to account for the non-occurrence of glide-retroflex sequences.

The *phonotactics* of the two fricative classes show no difference, but some behaviour in line with retroflexes (see (1e)): neither the apico-post-alveolar nor the subapical palatal fricative occurs in word-initial position (Sakthivel 1976: 56ff.).

Summing up these observations, the apical post-alveolars behave in some respects phonologically like retroflexes (for instance in its non-occurrence after the palatal glide), in others not (for instance it occurs with a following glide, and in high front vowel context). This result can interpreted in two ways, namely that it is possible to have (i) phonetically and phonologically two retroflex classes, or (ii) a phonetically retroflex, but phonologically non-retroflex class. In the first case, the two retroflex segmental classes nevertheless have to be phonologically distinguished, which is unproblematic if one departs from the traditional feature description of retroflexes as [coronal, –anterior, –distributed], as argued in section 5.2.3 below.

4.8 Conclusion

In this chapter it was illustrated that retroflex segments show cross-linguistically and diachronically homogeneous behaviour with respect to processes such as a preference of back vowel context, incompatibility of front vowel context, and so on. Furthermore, it was shown that this behaviour is phonetically motivated. and that this phonetic grounding can account for the similarity in synchronic rules and diachronic emergence of retroflexes.

Several of these processes have a preference for a specific order: rhotics causing retroflexion usually occur in front of the apical to be retroflexed, and front vowels that are changed in retroflex context are also pre-consonantal. Generalizing away from single processes, retroflexes preferably occur post-vocalically and affect preceding segments. This observation can be accounted for in several ways. First of all, the asymmetrical spread of cues as described in 3.5, with VC cues being stronger than the CV cues of retroflexes, is a cause for a restriction on the occurrence and the direction of influence. Furthermore, studies such as Krakow (1999) show a difference in gestural overlap between a consonant and a preceding vowel compared to a consonant following a vowel: the gestures are much better synchronized in CV gestures, but overlap for VC gestures. The gesture of retroflexion hence influences the preceding vowels, not the following ones.

With respect to the manner of the retroflexes involved in the different processes, some further generalizations can be made. If a single manner class and not the whole class of retroflexes is the trigger or the target of a process, then it is often a retroflex approximant that is changed due to its articulatory instability. Retroflex fricatives, on the other hand, often cause adjacent segments to change to a retroflex, because of their strong internal cues.

Noteworthy in the descriptions in this chapter is the similarity between retroflex segments and rhotics, see the restricted distribution of vowels in front of both (section 4.3),[55] and the retroflexion of both vowels (section 4.4) and consonants (section 4.1) in rhotic context. These processes are not restricted to apical rhotics, but can partly also be triggered by uvular rhotics, which indicates that it is not a common articulatory property between retroflexes and coronal rhotics (such as tongue tip articulation) but rather a common perceptual characteristic, namely the low F3, that accounts for the common restrictions.

The illustration of a cross-linguistically similar behaviour of the class of retroflexes is not taken as evidence for a universally valid category of retroflexes, let alone, for the innateness of features determining such a category. The rules and restrictions observed in this chapter fall out of the definition of the retroflex class in the preceding chapters 2 and 3. Due to the articulatory criteria of posteriority, apicality, retraction, and sublingual cavity, the so-defined class shares the same articulatory restrictions. Avoidance of front vowels and occurrence in back vowel context, for example, is due to apicality and retraction of the segments (as attested by the fact that other, non-anterior apicals share this property, cf. Bhat 1973). Thus, any segment that satisfies the articulatory criteria proposed in chapter 2 is bound to show this articulatory behaviour. Likewise, the retroflex class was defined as sharing the acoustic features of high/middle F2 and low F3, which account for their perceptual similarity with rhotics and back vowels.

The apical post-alveolar and the subapical palatal in Toda were both shown in section 4.7 to meet the articulatory properties of retroflexion and also to behave partly as retroflexes. If one universal category were assumed, then a language that has two segmental classes both belonging to one universal category would be problematic and impossible to account for.

Several points that were described in the present chapter are worth future research. For the process of retroflexion after rhotics (section 4.1), the question arises whether non-retroflex, non-coronal rhotics can really trigger retroflexion, too. This could be checked by a detailed investigation of the Southern Swedish dialect of Svantesson (2001) to decide whether its retracted alveolar segments fulfil the four articulatory properties of retroflexes developed here in chapter 2. If these segments turn out to be retroflex, this dialect will be an example language for retroflexion in non-coronal rhotic context.

Another point for further study is the diachronic development of retroflex segments from Classical Tibetan to Modern Sino-Tibetan languages (also section 4.1) and the question whether assimilation of velars and labials to coronals took place before retroflexion via rhotics occurred, or whether the velars and labials were retroflexed directly.

Concerning the affinity with back vowels illustrated in section 4.2 and the vowel-lowering processes from section 4.3, more diachronic and synchronic evidence for the articulatory similarity between retroflexes and mid back vowels rather than high back vowels is hoped to be found in the future.

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[55] An exception to this generalization is Scottish English, which can have all vowels before a rhotic (Harris 1994: 255).

The retroflexed vowels of Badaga, which illustrated vowel retroflexion in section 4.4, have to be investigated articulatorily to determine whether they include high front retroflexed vowels or whether the gap in Emeneau's (1939) data was not accidental.

Quite a number of retroflexes showed a dependence on segmental length or prosodic position, a point that was not the focus of the present study but which might yield interesting insights for prosodic theories.

Lastly, I hope that confirming evidence for the processes of retroflexion via velarization and rounding that were left undiscussed here, will be found as well.

5 Phonological representations of retroflexes

This chapter is concerned with formal phonological descriptions of retroflexes and the notion of phonological features. In the structure of the thesis, it is situated as follows: Chapter 4 illustrated cross-linguistic, phonological processes of retroflexion and de-retroflexion, and their phonetic grounding. The topic of the present chapter is a featural representation of retroflex phonemes that can account for these processes. A formal representation of retroflexion and de-retroflexion processes by means of these features is then presented in chapter 6.

In the present chapter I will argue that neither the traditional features [+coronal, –anterior, –distributed], nor their alternative within the framework of Feature Geometry (usually [CORONAL, –anterior, –distributed, +back]) suffice to account for the perceptually and articulatorily motivated processes described in chapter 4.

More phonetically oriented approaches in the framework of Optimality Theory, which separate articulatory and auditory representations and features, are invoked, and it is demonstrated that this separation is actually required to handle all of the data given in chapter 4. It will be claimed that the major shortcomings of almost all of the previous approaches is the requirement that features express natural classes. Following Pierrehumbert, Beckman & Ladd (1996) and Boersma (1998, 1999), it will be proposed that features are only universal in as far as they are grounded in the human vocal tract anatomy, the hearing system, and the mental capacity to categorize. Thus, I will assume no universally valid system of phonological features. Furthermore, I will argue that the attempt to differentiate phonological features and phonetic cues is often futile, and that phonetic cues are directly relevant for phonological processes and should therefore be able to function as features. A third point argued for here is that defining 'natural classes' that hold cross-linguistically is not a function of features, but a descriptive device for linguists that facilitates the comparison of language-specific processes across different languages.

The structure of this chapter is as follows. In section 5.1 the function of distinctive features in earlier approaches and in the present approach is defined. Section 5.2 presents the representation of retroflexes in the featural systems of Jakobson, Fant and Halle (1952), Chomsky and Halle (1968), and the theory of Feature Geometry. More phonetically oriented approaches to distinctive features are discussed in section 5.3. In section 5.4, I propose my own approach including perceptual features and restrictions on their articulatory realizations, based largely on Boersma's (1998) Functional Phonology. Section 5.5 concludes the chapter. No complete discussion and overview of the traditional and the phonetically oriented approaches is aimed at, instead the main concepts of these theories are presented with a focus on the featural representations proposed for retroflexes (even in this respect no attempt at completeness is made).

5.1 The functions of features

Before discussing the features (or, alternatively, cues) that are used for the representation of retroflexes in former approaches and in more recent ones, we have to clarify the function of phonological features. It is generally accepted that features are necessary to represent phonological processes in a language. I will term this the representational function of features. Furthermore, features have the classificatory function of encoding contrasts between segments in natural languages, which results in natural classes: segments that share a feature belong to a natural class. Evidence for such classes comes from phoneme inventories in natural languages and also from phonological rules referring to the feature and hence to these classes. An example illustrating these two functions of features is the feature [voice] which classifies obstruents as either voiced or voiceless. A number of languages such as Dutch and German show a process of final devoicing by which the voiced sonorants are realized as voiceless in the coda-position. This rule is evidence for the existence of the feature [voice] since only this feature is changed in the process of final devoicing, whereas all others are maintained.

Many authors (such as Chomsky & Halle 1968, and Ladefoged 1971, 1975) claim that a further function of phonological features is to ensure phonetic interpretability of the segments. Our example feature [voice] can be phonetically interpreted as vibration of the vocal folds for [+voice] segments among other phonetic correlates. The three functions are summarized in (1), together with the domain in which they apply.

(1)	i. representation	language-specific
	ii. classification	cross-linguistic
	iii. phonetic interpretability	language-specific

Lahiri & Blumstein (1984:133) state that "features provide the interface between the physical attributes of the speech sounds and their functional attributes in the phonological systems of natural language". From this position, we can derive a structure as in figure 5.1, see Lindau & Ladefoged (1986) and Nearey (1995: 29) on similar representations.

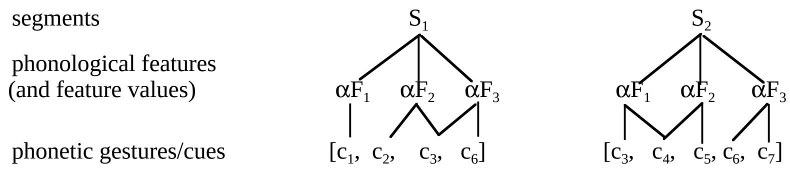

Figure 5.1 Schematic representation of relation segment – features – gestures/cues in traditional view.

According to this view, segments are made up of features, which in turn are correlated with acoustic cues and/or articulatory gestures, that is, with their physical attributes. Nearey (1995) calls the relation between the phonetic properties and the phonological features represented in his figure 3.2, which is similar to my figure 5.1, *many-to-many*, since several attributes can be associated with one feature and several features with one attribute, opposed to a *one-to-one* relation represented by Stevens & Blumstein (1981), where one feature is associated with one physical attribute. The latter view, which is very restricted, will not be further dealt with in this dissertation.

The representation of both the articulatory gestures and perceptual cues on one level in figure 5.1 is a simplification. In standard featural theories, gestures are assumed to be the primary correlates of the phonological features, from which perceptual cues are derived.

Furthermore, in standard featural approaches phonological features are universal and innate, that is, part of the Universal Grammar, and language learners use those features from the restricted innate set that are active in their language. All segments in all natural languages can be described with the same set of features. As Halle (1992: 207) puts it, "features, rather than speech sounds, are the ultimate building blocks of language". The phonetic realization of these features, however, i.e. the correlation between features and cues, is language-specific according to standard belief because languages differ in the way they phonetically realize featural contrasts.

Phonological features and their phonetic realizations differ not only in their claim to universality. Phonetic cues have a temporal structure within the segment, a stop burst or instance is situated after the stop closure and before the CV transitions, and cues do not necessarily hold for the whole duration of a segment. Some cues can even span two segments, consider the case of vowel transitions. Features, on the other hand, generally apply to the whole segment, although since the advent of Autosegmental Phonology (Goldsmith 1976) features are assumed to project their own tier, and thus can be assigned to a segment, a syllable, a phonological word, and so on. Units smaller than the segment (for instance single cues such as the silence of the stop closure)[1] are not accessible for autosegmental features.[2]

The search for universal features has been one of the main aims in phonological theory in the last half century. Cues, however, have only recently become a focus of interest for phonologists, for example in the rise of laboratory phonology (Kingston & Beckman 1990, Docherty & Ladd 1992, Connell & Arvaniti 1995, and others). Some of these more recent approaches suggest that the distinction between cues or gestures and features (or phonetic and phonological features in Steriade 2000) is superfluous, and that the two are the same. If so, a correlation as in figure 5.2 follows.

[1] The stop closure could be a useful autosegment in the description of stop gemination processes, since only the silence of the stop closure is stretched/doubled in geminates, while all other cues such as the stop release burst or vowel transitions are not affected by this process.

[2] The mora is a counterexample to this claim since it is a unit sometimes smaller than the segment that can be an autosegment. A mora, however, is an abstract descriptive unit without concrete physical correlates.

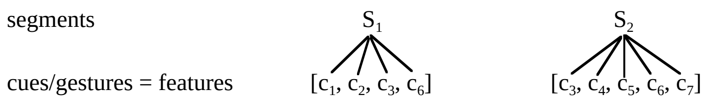

Figure 5.2 Schematic representation of relation segment – cues in phonetic approaches.

Phonologists such as Steriade (1995, 1997, 2001), Flemming (1995/2002, 1997), Boersma (1998, 2001), and others have shown in their work that phonological patterns can be explained by directly referring to the "details of their physical implementation" (Steriade 2000: 314). Their proposals will be discussed in sections 5.3.3 and 5.3.4. I will argue below that figure 5.2 is correct and that there is no need for traditional universal features as represented in figure 5.1.

5.2 Featural representations

The concept of features distinguishing the sounds of a language was initially developed by Jakobson and Trubetzkoy. According to Anderson (1985: 119), Trubetzkoy's *Grundzüge der Phonologie* (1939) can be described as the first attempt to provide "a universal framework of the features that are exploited for phonological purposes in the languages of the world as opposed to purely descriptive frameworks." The aim of Trubetzkoy's features is, however, to distinguish segments within a language, not to develop a universal feature system. The first full-fledged system of features was proposed by Jakobson, Fant and Halle (1952), and is outlined in section 5.2.1 below. The next influential feature system was developed by Chomsky and Halle's (1968), discussed in section 5.2.2. Both systems share the idea of the segment as an unordered bundle of features, which was replaced in later theories by hierarchical relations between features (to be discussed in section 5.2.3).

5.2.1 Jakobson, Fant, & Halle (1952)

Jakobson, Fant & Halle (1952) and Jakobson & Halle (1956) introduced a universal system of twelve distinctive features that were defined both acoustically and articulatorily. Most of these features refer to sounds which do not form a class in articulatory terms. The feature [grave], for example, specifies labial and velar consonants as well as back vowels. [grave] sounds show a low frequency concentration in the acoustic spectrum and are formed with a relatively large, undivided oral resonant cavity. The Jakobsonian features are unary, but as most of them have a complement feature that comprises all segments not included by that feature, for example [acute] being the complement of [grave], they can be reformulated as binary features (e.g. [±grave], where [–grave] stands for [acute]). The feature [flat] is an example of a feature that has more than one counterpart: non-flat sounds can be either [sharp] or [plain]. Sharp sounds show an upward shift in the upper frequencies of the spectrum and are articulated with a broad pharynx. The feature [sharp] is restricted to secondarily palatalized consonants, but does not include palatal consonants. [plain] refers to sounds that have a relatively closed pharynx and no shift in the upper frequencies. It comprises non-sharp and non-flat sounds.

Jakobson et al.'s work was written in the structuralist framework, and the main idea of this feature system is to specify phonemic contrast between segments. In this system, coronals are represented as [acute], which describes sounds that involve a division of the oral cavity into two smaller cavities, resulting in a prominent high frequency region in the acoustic spectrum. According to this definition, retroflex segments belong to the acute sounds as their post-alveolar constriction results in two resonators in the oral cavity (recall also the short description of [acute], [diffuse], and [flat] presented in section 3.1.7). The acute-grave distinction is cross-classified by the features [diffuse] and [compact]. Retroflex consonants, like all apical sounds, are specified by the feature [diffuse], which describes a constriction in the front of the oral cavity. Diffuse sounds do not have a spectral concentration of energy. Its opposite is [compact], defined as referring to sounds with a constriction in the back of the oral cavity and with an energy concentration in the central region of the spectrum.

As demonstrated in chapter 3 on the acoustics of retroflexes, retroflexion results in a downward shift of the upper frequencies in the spectrum. In Jakobson et al.'s terms, this is specified by the feature [flat]. The same acoustic effect of 'flatness' can be achieved by lip-rounding, velarization or pharyngealization, which illustrates that the feature [flat] is only an additional specification and cannot contrast a retroflex and a rounded segment with otherwise identical features. In sum, retroflex segments are [acute, diffuse] in Jakobson et al.'s terminology, and an additional specification by the feature [flat] is possible if necessary for further distinction. This is, for example, the case for those Australian languages with two laminals and two apicals such as Pitta-Pitta (Dixon 1980: 134). A feature specification for such a language according to Jakobson et al. is depicted in table 5.1.

Table 5.1 Jakobson, Fant & Halle's (1952) features applied to a language with a four-way coronal distinction.

	p	t̪	t	ʈ	t̠(ʃ)	k
[compact]					+	+
[diffuse]	+	+	+	+		
[acute]		+	+	+	+	
[grave]	+					+
[flat]	+			+		

The feature system of Jakobson et al. is insufficient for describing and distinguishing all four coronals plus labial and velar place of articulation: as table 5.1 illustrates, the features do not distinguish between dentals and alveolars, which have identical feature specifications. The retroflex class can only be distinguished from the dentals and alveolars by the feature [flat], which is therefore a necessary specification in languages with large inventories.

Jassem (1979) uses Jakobson et al.'s features successfully for the characterization of Polish fricatives. Shalev et al. (1993), however, show that this feature system is not sufficient for the description of the large fricative inventory of Toda (recall this inventory from (5) in section 2.2.4.2). For another application of the Jakobson et al. feature system see the discussion of Hamilton (1996) in section 5.3.2 below.

5.2.2 Chomsky & Halle (1968)

In *The Sound Pattern of English* (henceforth SPE), Chomsky & Halle (1968) introduce a system of features which is based exclusively on articulation,[3] and which includes reformulations of Jakobson et al.'s features in articulatory terms. The former classification of grave-acute sounds, for example, is carried out by the feature [±coronal] in SPE, where the definition of [+coronal] does not refer to the acoustic property of prominent high frequencies but to the articulation with the tongue tip or blade. This formulation results in slightly different natural classes as [–coronal] includes palatals which were not included in the feature [grave] (see table 5.1).[4] As in Jakobson et al.'s proposal, the more than 20 features in SPE are proposed for classificatory purposes. But in contrast to previous approaches, SPE features also have a direct phonetic function: they are specifically designed to describe 'the speech producing capabilities of the human vocal apparatus' (SPE: 297). Thus, SPE aimed at a phonetic grounding of universal features in the articulatory system.

Retroflexes are classified as [+coronal] in the SPE system (SPE: 304). Coronal and non-coronal sounds are supplemented by the feature [anterior]: every place of articulation from the lips up to the alveolar region is [+anterior]. Hence retroflexes are [–anterior]. For a further distinction of [+coronal] sounds in the post-alveolar region, as for instance needed for Australian languages, the feature [distributed] is used: "distributed sounds are produced with a constriction that extends for a considerable distance along the direction of the air flow" (SPE: 312). Retroflexes, which are articulated with a short length of constriction, are [–distributed]. The full specification with SPE features for a language with four coronals is given in table 5.2.

Table 5.2 SPE features applied to a language with four-way coronal distinction

	p	t̪	t	ʈ	t̠	k
[coronal]	–	+	+	+	+	–
[anterior]	+	+	+	–	–	–
[distributed]	+	+	–	–	+	+

[3] The only exception seems to be the feature [strident], defined as sounds that are marked acoustically by greater noisiness than their nonstrident counterparts (SPE: 329).

[4] Furthermore, uvulars and pharyngeals are unspecified for [grave] in Jakobson et al. but are [-coronal] in SPE. Keating (1988a: 4), however, points out that, according to the definitions in Jakobson et al., uvulars and pharyngeals are plausibly [+grave].
For a discussion of the advantage of retaining [grave] instead of [coronal] see Hyman (1973) and Odden (1978).

In contrast to the terms referring to the articulator, the feature 'distributed' is not restricted to consonants articulated with the tongue tip only, but is also used to distinguish between labials [+distributed] and labiodentals [–distributed], and between velars and uvulars. As Keating (1988a) points out, this results from the tendency in SPE to use one feature to distinguish as many sounds as possible.[5]

Chomsky & Halle discuss Ladefoged (1964), who notes a difference between the retroflex segments of Ewe and the retroflex sounds found in the languages of the Indian subcontinent. SPE comments on the consequences of these inventories for the phonological representation:

> If this difference were systematic, it would clearly have to be reflected in the grammars of these languages. It is, however, quite sufficient to note that the point of contact between the tongue and the roof of the mouth is somewhat more advanced in one language than the other. This fact would presumably be reflected in low-level phonetic rules that assign numerical values to the different features. The existence of a systematic phonetic difference does not, therefore, in itself constitute a necessary and sufficient condition for postulating an additional point of articulation. (SPE: 313)

The standard view at that time of distinguishing universal phonological features from language-specific phonetic interpretation rules becomes obvious in this quotation. Only if a language were found to phonologically contrast both retroflex articulations, would a universal feature to distinguish the two articulations be introduced.

The reduction of features to just those which are phonologically relevant, and the optimal use of features for several distinctions at the same time (as in the case of [distributed]) often conflicts with the aim of including in the feature system the phonetic restrictions of the vocal apparatus. Some of the resulting shortcomings are illustrated in the following section on Feature Geometry.

5.2.3 Feature Geometry

The theory of Feature Geometry (henceforth FG, early key literature is: Clements 1985, Sagey 1986, McCarthy 1988) will be discussed in relatively great detail as it offers several possible accounts of the representation of retroflexes. It will be shown that none of them can capture all three functions of features as outlined in (1), especially the claim of universal applicability is problematic.

This section is subdivided as follows: In 5.2.3.1, the basic notions of FG are given, section 5.2.3.2 illustrates the different proposals on how to deal with vowel interactions of retroflexes, and section 5.2.3.3 briefly describes why FG fails to fulfil its aims in the areas under investigation.

5.2.3.1 Basic notions

FG basically introduces a hierarchical structure to Chomsky and Halle's features. Whereas SPE uses the binary features [±coronal] and [±anterior] to classify all

[5] One shortcoming of such an approach is that the features that are maximally used do not necessarily reflect natural classes, as is for instance the case for the class of [±anterior] sounds, see section 5.2.3.2 below.

sounds according to their place of articulation, FG introduces the privative place nodes LABIAL, CORONAL, and DORSAL (under a common PLACE node)[6], which correspond to three articulators. These three articulatory features dominate other features, as in figure 5.3 below. The reason for positing privative features is that the classes made up of the negative value of the SPE features 'coronal' and 'anterior' have been argued not to form a natural class. The class of [–coronal] sounds, including labials, palatals and velars, is now split up into the LABIAL node (formerly specified as [–coronal +anterior]) and the DORSAL node (formerly [–coronal –anterior]). According to Hume (1994: 21), this description with (privative) nodes "expresses more accurately natural phenomena such as assimilation and the behaviour of complex segments". Place assimilation for example can be expressed in FG as the spreading of the PLACE node. Furthermore, the SPE features 'distributed' and 'anterior' are now restricted to the coronal node and therefore receive a different interpretation. The new value [–distributed] now stands for an apical articulation, [+distributed] for a laminal, which led some phonologists to propose the replacement of [±distributed] by the privatives 'apical' and 'laminal' (see Gnanadesikan 1994, Hamilton 1993, 1996, Walsh Dickey 1997).

Figure 5.3 from Clements (1991: 28f.) illustrates the hierarchically structured features within his FG version.

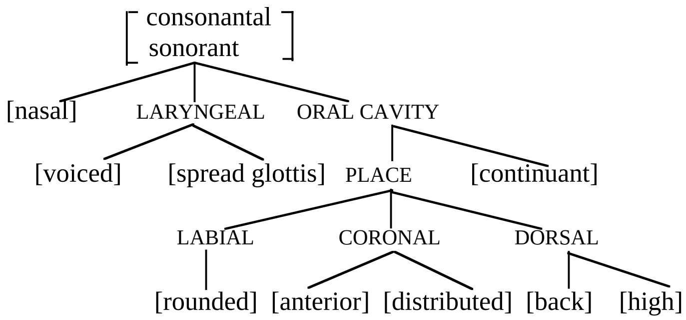

Figure 5.3 Hierarchical ordering of features according to FG in Clements (1991).

Besides the hierarchical ordering, FG also incorporates the idea of non-linearity of features developed in autosegmental phonology (Goldsmith 1976). Features are arranged on their own tier and can apply if necessary to a sequence of sounds, a whole syllable or a phonological word instead of just the segment.

In FG retroflexes are usually specified as [CORONAL, –anterior, –distributed] (as in Clements 1991). The values for the features [anterior] and [distributed] for coronal consonants are not different from those in SPE terms, compare table 5.3 to table 5.2 above, but receive a different interpretation, as elaborated above.

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6 RADICAL is often assumed to be an additional node under PLACE, see for instance Pulleyblank (1988), who proposes it for the specification of segments that are articulated with the tongue root, such as [ʕ ħ]. Clements (1991) includes the feature [low] under the DORSAL node as well, but as that is not common it is left out here.

Table 5.3 FG representation of a language with a four way coronal distinction

	t̪	t	ʈ	t̠
[CORONAL]	√	√	√	√
[anterior]	+	+	–	–
[distributed]	+	–	–	+

In table 5.3 and below '√' denotes the presence of a privative feature.

Within FG, several proposals were put forward especially for the representation of coronals and their interaction with vowels, particularly in literature such as Pulleyblank (1989) and Hume (1992). The following subsection describes these proposals and their consequences for the representation of retroflexes.

5.2.3.2 Proposals for retroflexes patterning with vowels

Chapter 4 illustrated that retroflexes show an affinity to back vowels and a dispreference for front vowels. To account for these correlations, many authors propose one feature with the same value for back vowels and retroflexes and an opposite value for front vowels. The proposed feature is usually [back], although some phonologists (such as Pulleyblank 1989) propose [front]. These features are either under a separate dorsal node or they replace one of the coronal features [distributed] or [anterior], see (2) for a list of the proposals.

(2) (a) additional DORSAL feature (Sagey 1986, Pulleyblank 1989)
(b) retroflexes as language-dependently [±back] (Hall 1997)
(c) replacement of [distributed] by [back] (Lin 1989, Rubach 1984)
(d) replacement of [distributed] by [front] (Pulleyblank 1989)
(e) replacement of [anterior] by [back] (Gnanadesikan 1993)

An additional DORSAL feature [back] for coronal segments, see (2a), is used by Sagey (1986) and others to indicate secondary articulations: [+back] coronals are velarized, and [–back] coronals are palatalized. According to this definition, retroflexes should be specified as [+back], because they have a retracted tongue body, i.e. they are velarized. This representation is, however, not obligatory, as pointed out by Hall (1997: 49f.). Hall therefore proposes to distinguish non-velarized from velarized retroflex segments by representing the latter with an additional feature [+back], see (2b). The two different representations are given in (3).

(3) [ʈ] = [CORONAL, -anterior, -distributed]
[ʈˠ] = [CORONAL, -anterior, -distributed, +back]

According to Hall, the choice between these two segment classes is language-specific. Such a representation implies that only velarized retroflexes show an affinity with back vowels. The representation proposed by Hall is based on the assumption that languages such as Lardil have non-velarized retroflexes. But in chapter 2 I illustrated that retroflexes are generally retracted. The two possible counterexamples of Lardil and Badaga were shown in section 2.3.4 actually not to have non-velarized retroflexes. Thus, I argue here that the distinction proposed by Hall is invalid.

Rubach (1984), Lin (1989: 61), and others propose the replacement of [distributed] by [back], see (2c), which has the consequence that retroflexes are CORONAL [+back] instead of [–distributed]. The resulting natural classes are exactly the same as in the classical FG approach, see table 5.4 vs. 5.3.

Table 5.4 Featural representation with [back] instead of [distributed].

	t̪	t	ʈ	t̠	i	u
[CORONAL]	√	√	√	√	√	√
[anterior]	+	+	–	–		
[back]	–	+	+	–	–	+

Front vowels can now be represented by the coronal feature [–back], and back vowels by [+back], ensuring the correlation with retroflexes. But whereas [distributed] was defined by the length of the constriction, [+back] is defined as a raised tongue back, i.e. it has the phonetic correlate of velarization. The feature replacement thus implies that all apical sounds have a raised tongue body, an assumption that is an overgeneralization as apical alveolars can be non-velarized, recall the discussion of apicals and retraction in section 2.3.4.

The same classes that are predicted by the coronal feature [back] also result from Pulleyblank's (1989) proposal to replace [distributed] with [front], see (2d). In addition, Pulleyblank does not have the feature [anterior], but instead introduces the DORSAL feature [high] to further distinguish coronal sounds, as illustrated in table 5.5.

Table 5.5 Featural representation according to Pulleyblank (1989).

	t̪	t	ʈ	t̠	i	u
[CORONAL]	√	√	√	√	√	√
[front]	+	–	–	+	+	–
[DORSAL]	√	√	√	√		
[high]			+	+		

The feature [front] has the opposite values of the feature [back], but as the values plus and minus do not have any implication for the resulting classes, this fact can be ignored. As front vowels are [+front] and back vowels and retroflexes [–front], the interactions of vowels and retroflexes can be captured in this system. Phonetically, [+front] is realized as a tongue front raising, which is not present in retroflexion, thus a specification for retroflexes as [–front] is appropriate. The DORSAL feature [+high] is not further defined by Pulleyblank. Its restriction within the coronals to retroflexes and palato-alveolars is unmotivated.[7] Phonetically, these two sound classes do not share a shape of the tongue body distinguishing them from the other

7 Pulleyblank's restriction of [+high] to retroflexes and palato-alveolars implies that these classes are structurally more marked than alveolars and dentals, which is supported by Pulleyblank's remarks on the allophonic behaviour of coronals in Australian languages (p. 385).

two coronals, they have only a post-alveolar place of articulation in common. Phonologically, there is no evidence for this class, either. Both the proposal by Pulleyblank and those by Rubach and Lin described in the paragraph above run into a problem with the representation of the *nati* rule in Sanskrit (see section 4.6.2): with traditional features, the retroflexion of an apical nasal after a (non-adjacent) retroflex fricative can be described as a spreading of [–anterior] from one [–distributed] segment, the retroflex, to the other, the nasal. Intervening [+anterior] segments block the process. If, however, apicals and retroflexes were specified by [back] or [front] instead of [–distributed], then the long-distance assimilation of the *nati* rule would be blocked by other segments that are specified by these features such as velars.

Another proposal to formalize the interaction of coronals with vowels is to replace [anterior] by [back], see (2e) (Gnanadesikan 1993). This proposal hinges on the claim that the feature [anterior] does not describe a natural class. For a discussion of the (non-)naturalness of the classes yielded by [+anterior] and [–anterior] see McCarthy (1988), Pulleyblank (1989), and Hall (1997: 45f.). A feature specification for coronals resulting from the replacement of [anterior] by [back] looks like the following, where dentals and alveolars are unspecified for the feature [back].

Table 5.6 Featural representation without [anterior] (Gnanadesikan 1993).

	t̪	t	ʈ	t̠	i	u
[CORONAL]	√	√	√	√	√	√
[distributed]	+	–	–	+		
[back]			+	–	–	+

In this representation, front vowels could be specified as [–back] and back vowels as [+back] to formalize the interaction with the retroflex class. Like Pulleyblank's approach, a representation such as that in table 5.6 also presupposes that laminal dentals and apical alveolars are structurally less marked than retroflexes and laminal palato-alveolars (see footnote 7). A universal assumption such as this is, however, problematic: recall for instance that retroflexes did not show phonotactic markedness in all languages, see section 4.5.2.

In sum, none of the proposals discussed above satisfies all three functions of features. Some proposals are phonetically non-interpretable, others predict non-occurring classes. Pulleyblank's feature value [+high] for retroflexes and palato-alveolars is an example of both: the phonetic equivalent of [+high] is not clear, plus the two sound classes do not share a tongue gesture that could be referred to by this feature. The majority of proposals fails to be universally valid, such as the DORSAL specifications of retroflexes as proposed by Pulleyblank, Sagey, and others, or the representation of apical alveolars as universally velarized, as in Lin and Rubach.

5.2.3.3 Why does FG fail?

As shown in the previous section, there is no consensus on how to represent retroflex segments in a feature geometric approach. Different proposals are made depending on the language or language group under scrutiny. This discrepancy in the presentation hinges on four major flaws of FG, all stemming from the three-fold function assumed for features: the assumption that there is one universal hierarchy (classificatory function), the irreconcilability of this universality with language-specific processes (conflict between classificatory and representational function), and the restriction to articulatory features and over-simplification of the dependency relations in the vocal apparatus (both miscomprehensions of the function of phonetic interpretability).

Let us look at the *universality of features* first. The fact that no single geometrical arrangement of features seems to hold for all languages was pointed out by Mester (1986): "some properties of Feature Geometry, in particular dependency relations between features, vary from one language to another". This problem can be solved in two possible ways. The first one is to assume a universal order of features, without all features being employed or activated in all languages. This approach is put forward by Clements (1999, 2001) who posits tiers that are not relevant in every language, but are inactively present. The activation of relevant tiers is done via the "Prominence Criterion": in any language, all and only prominent features and nodes are projected onto separate autosegmental tiers. This idea is compatible with the notion of parameters, which decide on the presence or absence of features and their combination (compare Cho, 1991 who introduces the parameter [COR] or [–cor]). Even this alternation runs into problems with languages such as Toda with a large coronal fricative system that contains two retroflex classes, see sections 2.2.6 and 3.3.2.3. Since the features [distributed] and [anterior] and their articulatory definitions yield no way of distinguishing between an apical post-alveolar and an subapical palatal articulation (both classes are [–anterior, –distributed]), the Toda classes cannot be distinguished by these traditional features.

A second solution to the problems following from universal features is to assume that phonological features are not innate, but that they show cross-linguistic similarity due to the restrictions of the vocal and hearing apparatus, and the classificatory abilities of the human. This functional approach is represented by Boersma (1998), illustrated in section 5.3.4 below. According to this functional view, the articulatory and perceptual systems are universal, but a phonological use of them is language-dependent: hence a phonological theory built on universal features is bound to fail.

A further point of criticism is that the features employed in FG are almost only based on articulation, as illustrated by Flemming (1995). This *articulatory bias* is problematic. Some phonological processes are triggered by perceptual similarity, which is not captured in an articulatory feature system; this was pointed out for instance by Ohala (1989, 1993) in a description of perceptual cues playing a role in sound change. The problem of the general restriction to articulatory features becomes obvious with the re-introduction of Jakobson et al.'s perceptual feature [grave], which combines velars and labials as sounds with an energy concentration in the low frequency area, as the articulatorily defined feature [peripheral] under the PLACE node (Dogil 1988, Avery & Rice 1989, Rice 1994, Hall 1997). Articulatory and perceptual features are both necessary in an account of phonological processes, as will be illustrated for the class of retroflexes in chapter 6. Furthermore, the two sets of features have to be distinguished in representations. Proposals along this line and their advantages are discussed in section 5.3 below.

In addition to being restricted to articulatory features, FG shows an *oversimplification of the vocal tract anatomy* and introduces some pseudo-articulatory nodes which are not motivated from an articulatory point of view. Ohala (1992: 178f.) is one of those who pointed out that the interaction of the glottal and the supraglottal domain is far more complex from an aerodynamic view than is presented in FG. Furthermore, the division of the tongue into CORONAL and DORSAL (and sometimes RADICAL) nodes has to be questioned. Coronal and dorsal articulations are treated as independent from each other, and so are anterior and non-anterior coronals. It has been illustrated in chapter 2 for retroflexes that this class shows a very complex interaction of the front, middle and back of the tongue: the raising of the tongue tip causes a lowering of the middle and a retraction of the back of the tongue, which accounts for some of the phonological behaviour of retroflexes (as illustrated in chapter 4). This interaction has to be represented in FG by referring to two different articulator nodes. In addition, the border between the coronal and dorsal classes is not well motivated. A long-standing debate is, for instance, the status of palatal consonants and whether they are coronal or not (see Hall 1997 for an overview of this discussion). Phonetic and phonological evidence was also brought forward for a complex articulation of palato-alveolars with both coronal area and dorsum involved, see for example Recasens et al. (1995) and Gussenhoven & Jacobs (1998: 199f.). A possible account of such interrelations of the tongue movements is proposed in 5.4.2 below.

A further point of criticism concerning the oversimplification of FG is that the articulators are all dependents of the place node. The only need for the place node is to explain assimilation processes, where one place of articulation is replaced by another, depicted as spreading and deletion of the place node. Boersma (1998: 442) points out that the three articulators grouped under the place node are articulatorily mainly independent of each other, and that the LABIAL, CORONAL, and DORSAL groupings arise because they happen to share the same influence on perceived nasality. Thus there is no reason why they should be subsumed under one node indicating one class. I agree on the needlessness of the place node. For the representation of retroflex assimilation processes without a place node see section 6.3.7.

As illustrated in section 5.1 above, it is traditionally assumed that phonological features should describe natural classes, yield a tool to describe the phonological processes in a given language, and ensure phonetic interpretability. These *three functions of features*, which are inherently assumed in FG, are conflicting. A description of natural classes occurring in the languages of the world calls for a minimal set of features in order not to overpredict any classes. The features for such a purpose do not have to be phonetically interpretable; on the contrary, a very abstract system that is free of phonetic substance is open for phonetic interpretation in single languages and is thus more useful for this classification task. The functions of phonetic interpretability and describing phonological processes, on the other hand, ask for different features. As observed by Kingston & Diehl (1994) and others, features differ in their phonetic content from language to language, depending on the number and ways of contrasts the respective language employs. The combination of features associated with single segments differs accordingly (Pierrehumbert, et al.1996: 142), thus a universal abstract set seems inappropriate. Furthermore, phonological processes in specific languages often refer to phonetic detail (illustrated in section 5.3 below), hence their representation needs to be fine-grained, with phonetically based features. An alternative view solving this problem is proposed in section 5.4 below.

5.3 Alternative approaches

This section discusses recent modifications of or alternatives to the previously presented feature theories, which improve the representations of retroflexes and solve some of the problems encountered by FG. All of these proposals were developed within the framework of Optimality Theory (henceforth: OT; Prince & Smolensky 1993) as this theory provides the possibility of formalizing interactions of articulatory and perceptual motivations for phonological processes.

In subsection 5.3.1, Flemming's approach is illustrated, in section 5.3.2 that of Hamilton, in 5.3.3 the proposal made by Steriade, and in section 5.3.4 the theory of Boersma. These four are chosen here for two reasons. Hamilton, Flemming, and Steriade deal with perceptual motivations for processes, specifically those involving coronals. Flemming and Hamilton propose perceptual representations to account for these processes, whereas Steriade proposes the device she dubs a 'perception map' to integrate information on perception into phonological accounts. Both Flemming and Steriade are concerned with processes involving the class of retroflex segments. Boersma is included although he does not explicitly treat retroflexes or coronals. However, his work provides a full-fledged model of perceptual features and their functioning in a perception and articulation grammar, and a slightly modified version of Boersma's proposal will serve as the framework for my own analysis in chapter 6, see section 5.4 below.

5.3.1 Flemming: Dispersion Theory of Contrast

Flemming's (1995) dissertation "Auditory Presentations in Phonology" (revised in 2002)[8] is of importance for the present work as it incorporates features based on perception (which Flemming calls auditory features) into phonological representations. Furthermore, it illustrates a formal analysis for the auditory motivation of rounding in retroflex contexts.

Flemming argues for the necessity of parallel articulatory and auditory feature representations, and assumes that the relationship between the two is determined by articulatory-to-acoustic mappings (2002: 4). Within an OT framework, the two representations are subject to two distinct constraint families, where constraints on the distinctiveness of segments refer to the auditory representations, and constraints on

8 The differences between the two versions will be indicated where appropriate.

the effort of gestures to the articulatory representation. The main idea is that a segment class is not inherently marked, but can only be marked with respect to its contrastiveness to other segment classes in the same inventory. The analysis of the maximal perceptual distance between segments within one language is what Flemming terms the “Dispersion theory of contrast”, after Lindblom’s (1986) “Theory of Adaptive Dispersion.” According to this theory, selection of contrast is based on the three following principles:[9]

(4) i. Maximize the number of contrasts
ii. Maximize the distinctiveness of contrasts
iii. Minimize articulatory effort

These principles are implemented in the Dispersion theory as markedness constraints on output forms.

Contrary to standard optimality-theoretic analyses, the Dispersion theory does not include constraints that require faithfulness to underlying forms. Flemming argues that faithfulness constraints are not necessary in his theory, they are even incompatible with it (2002: 33) since the aim of Dispersion theory is to account for inventories in general, independent of language-specific inputs.

To compare the contrastiveness of segments, Flemming assigns segments values for auditory features on what he calls ‘dimension scales’, as illustrated in (5a) for the F2 frequency (p. 94), and (5b) for the noise frequency (p. 55).[10]

(5) (a) F2 dimension

1	2	3	4	5
i	y	ɜ	ɯ	u
	ø			

(b) Noise frequency (NF)

1	2	3	4	5	6
χ	ʂ^w	ʂ	ʃ	s^w	s
		ʃ^w	ɕ		
		ɕ^w			

On the F2 scale in (5a) the value 1 stands for high F2, 5 for low F2, and on the noise frequency scale in (5b) 1 stands for low noise and 6 for high noise. Independently of the values used, Flemming’s scales represent some ordering of segments with respect to a single feature and therefore allow a direct comparison of the auditory distance between sounds. The term ‘scale’ is problematic, as it implies a scalar measurement, i.e. equal distance between the items, which is actually not present in these orderings. The distance in noise frequency between the fricatives [χ] and [ʂ^w], for example, cannot be assumed to be the same as the distance between [ʂ^w] and [ʂ].

Flemming’s evidence for auditory representations in phonology comes from three types of phonological phenomena: enhancement, assimilation, and neutralization. All of these involve auditory contrasts between segment classes. Examples

9 Functional principles such as those in (4) are not new to phonological theory, see for example literature as early as Passy (1891), although Flemming fails to mention this.

10 In his earlier (1995) version, Flemming uses binary auditory features instead of scalar ones. The scale for F2 is subdivided into the features [highest F2, high F2, low F2, lowest F2]. This change is neither mentioned nor explained in the later version (2002).

with retroflex segments are given for all three processes: enhancement is shown by the rounding of retroflexes, see (6),[11,12] assimilation by the rounding of front vowels in retroflex context, see (7), and neutralization by coronal neutralization, see (8).

(6)	*Enhancement*		
	(a) retroflex fricatives are rounded	ʂ → ʂ^{w}	in Polish
	(b) retroflex approximants are rounded	ɻ → ɻ^{w}	in English
(7)	*Assimilation*		
	rounding of vowels adjacent to retroflexes	iʈ → yʈ	in Wembawemba and Wergaia
(8)	*Neutralization*		
	only retroflexes occur in initial and postconsonantal position	Ct ~ Cʈ → Cʈ	in Gooniyandi and Walmatjari

Flemming motivates the rounding of the retroflex fricative in Polish[13] in (6a) by the presence of two other coronal fricatives in Polish, namely [ɕ] and [s̪] (p. 56). The rounding occurs in order to make the retroflex auditorily more distinct from the alveolo-palatal [ɕ] on the noise frequency scale. As we can see on the scale given above in (5b), the pair [ʂ - ɕ] has a difference of one scale-unit of noise frequency, whereas [ʂ^{w} - ɕ] has a difference of two, thus the contrast in the Polish fricative inventory is enhanced by rounding. Mandarin, not discussed in Flemming's dissertation, has the same sibilant inventory as Polish (Ladefoged & Maddieson 1996: 150f.), although the retroflex is not rounded. Mandarin thus does not enhance the auditory distinction between the retroflex and the alveolo-palatal sibilant. In Flemming's theory, the difference between Mandarin and Polish cannot be accounted for by refering to different underlying input forms since the Dispersion theory does not take underlying representations into account. Presumably, these language-specific differences can be explained by a constraint militating against an additional articulation of rounding being ranked higher in Mandarin than in Polish.

With respect to the rounding of the English approximant in (6b), Flemming explains that lip rounding serves to further lower the F3 of the retroflex, thus "enhancing contrasts on this dimension" (p. 56). Which contrast has to be enhanced is not further specified by Flemming, but we can assume that it is the one between the approximant and the lateral [l] in English.

Examples of the process of vowel rounding adjacent to retroflexes in Wembawemba and Wergaia, see (7), were presented in section 4.3.2.4, where it was also explained that this process is articulatorily motivated by the incompatibility of the high front vowel gesture with the retraction of the tongue body necessary for retroflexion. Flemming also assumes an incompatibility of retroflexion and high front

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11 Flemming transcribes the retroflex approximant with the symbol [ɹ].

12 In Flemming's account the process of rounding is not restricted to retroflex fricatives but is also shown to occur with [–anterior] segments, and he exemplifies rounding of laminal post-alveolars with the process ʃ → ʃ^{w} in English and French (p. 55).

13 According to Ladefoged & Maddieson (1996) the Polish retroflex fricative shows lip-protrusion, not rounding. Lip protrusion causes the vocal tract to be lengthened, which results in lower formant frequencies. Lip rounding is a closing off of the vocal tract on one side, which has a lowering effect on F3, so both lip movements have similar acoustic results.

vowel gesture, and points out that the rounding of the vowel serves to enhance the retroflex perception, as the retroflex gesture is reduced or even lost in this context (in his analysis Flemming presumes the complete loss of retroflexion). One question arises here: if the retroflexion of the consonant is supposed to be enhanced, why is it the vowel that is rounded, and not the retroflex itself, as is the case with the Polish fricative and the English approximant in (6)? The two possibilities are illustrated in (9).

(9) (a) iʈ → yt (b) iʈ → it^w

The rounding of the vowel as in (9a) jeopardizes the distinctiveness of the vowel as well as that of the consonant: the vowel is rounded and hence is closer to the back rounded /u/ in both languages, and the retroflex is changed to a non-retroflex coronal, making it indistinguishable from the front coronal. If maximal contrastiveness is assumed, as in Flemming's Dispersion theory, one would expect a development as in (9b), where the original retroflex is rounded to enhance its contrast with the non-retroflex coronal. However, the segments undergoing de-retroflexion in Wembawemba and Wergaia are plosives, and secondary rounding of plosives can be perceived in the release phase only. Retroflexion of the vowel, on the other hand, is perceivable throughout the vowel segment. This factor of cue perceptebility obviously influences the choice of the segment that undergoes rounding, i.e., this is a case of cue enhancement.

Flemming also discusses processes where mid front vowels are lowered in a retroflex context (pp. 90ff.). He distinguishes vowel rounding and vowel lowering, assuming that the first occurs only for high front vowels which make a retroflex gesture impossible, whereas the latter occurs with mid front vowels, where slight retroflexion is possible if the vowel is lowered. Thus, the rounding of the vowel is necessary only when a retroflexion gesture is articulatorily impossible.

Apical positional neutralization in (8) was already illustrated in section 4.5. Flemming (2002: 43f.) follows Steriade's (1995, 2002) analysis of this process (see section 5.3.3 below), and argues that this neutralization is caused by a lack of contrast between the apical alveolar and the retroflex in initial position. In this position, the VC transitions are not available since no vowel precedes, and the available CV cues are very similar for retroflexes and front apicals. The distance between the F3 in the release is only one unit on Flemming's F3 scale, see (10).

(10)

	ʈ		t̺, t̪, t̠	
	approach	release	approach	release
F3	2	4	5	5

Flemming also explains that despite their more complex articulation, retroflexes can occur in the site of neutralization. This is due to the fact that their F3 releases are distinct from those of all other coronals, as can be seen in (10) (other cues distinguishing the four coronals are not known and therefore not specified in this analysis).

In general, the need for auditory representations is well-motivated in Flemming's dissertation by various processes that cannot be accounted for with articulatory features. Flemming's Dispersion theory, however, has a big drawback. It is a model to evaluate inventories only, which is done by comparing output representations. Input representations are irrelevant for this theory. As pointed out by Boersma (1998: 361), the Dispersion theory is therefore not a model of a production grammar, i.e., cannot account for the mapping of an underlying form to a surface form.

The articulatory representations employed by Flemming are given in the traditional features in a FG hierarchy, although the insufficiency of these features becomes obvious when the tongue body position has to be specified (which is done with the features [high] and [front]), or different degrees of retroflexion are needed (there is only the binary feature [anterior] which specifies either full retroflexion or none). The traditional featural representations for these are modified in Flemming's analysis of retroflexion in (high) front vowel context, by a scalar representation of the feature [anterior] as [−1ant] for full retroflexion, [0ant] for partial retroflexion, and [+1ant] for anterior coronals. Furthermore, a backness dimension is introduced, which is divided into [–2back] for a front tongue body, [0back] for central, and [–1back] for an intermediate position. In brackets Flemming adds that positive values would represent a back tongue body position. Flemming's changes of these features support the point made in section 5.2 above that FG features are insufficient for the representation of phonological processes involving retroflexes and other segments. Furthermore, Flemming's work illustrates the need for phonetically rich phonological representations.

5.3.2 Hamilton: Gestural and Perceptual Theory of Markedness

Hamilton's (1996) dissertation deals with the phonotactic restrictions on coronals in Australian languages and argues that these are phonetically grounded.[14] The actual data and their explanation were already discussed in section 4.5. The present section is only concerned with Hamilton's theoretical assumptions and their formalization. According to Hamilton, unmarked clusters are gesturally and/or perceptually simple, whereas marked structures are gesturally and/or perceptually complex. These basic ideas are couched in what he calls the "gestural and perceptual theory of markedness", given here in (11) and (12) (p.9ff.):

(11) *Gestural Theory of Markedness (GTM)*:
Simple gestures are less marked than complex gestures.

(12) *Perceptual Theory of Markedness (PTM)*:
Perceptually simple speech sounds are less marked than perceptually complex speech sounds.

A 'simple gesture' is defined as one involving articulatorily less effort than a complex one, and a 'perceptually simple speech sound' is defined as one that has robust

[14] Hamilton's analysis is restricted to morpheme-internal phonotactics because "the set of consonant clusters which occur at morpheme junctures on the surface are typically less restrictive than what is attested morpheme internally" (p. 18).

spectral cues. The resulting two markedness hierarchies are assumed to be language-independent, and could be formalized as fixed rankings of markedness constraints in an OT framework, which is a s step that Hamilton suggests but does not take himself. According to Hamilton, the ranking between GTM and PTM constraints has to be language-specific.

Reference to perceptual simplicity and perceptual cues implies that Hamilton includes perceptual features[15] in his phonological representations. The perceptual features he proposes are based on the feature system of Jakobson et al. (1952) and Jakobson & Halle (1956) (see section 5.2.1). Hamilton replaces the unary features [acute] and [grave], by [±grave], and [compact] and [diffuse] by [±compact], thus reducing the original system. Furthermore, he uses the feature [sharp] for distinguishing primary places of articulation, and not to refer to secondary palatalization as originally defined: laminal palato-alveolars are [+sharp] because of their high F3, all other coronals are [–sharp].

Table 5.7 Hamilton's (1996) acoustic features (an empty field indicates no specification for this feature).

	labial	laminal dental	apical alveolar	laminal pal.alv.	retroflex	velar
grave	+	–	–	–	–	+
sharp		–	–	+	–	
flat		–	–	–	+	
compact	–					+

The non-distinctiveness between laminal dentals and apical alveolars reflects their similar formant transitions (recall the discussion in 3.3). Hamilton provides no solution on how to distinguish between laminal dentals and apical alveolars in languages that contrast these two classes.

In addition to the acoustic features in table 5.7, Hamilton introduces a set of articulatory features which differs slightly from the standard ones of FG. Hamilton (1996) proposes the unary features [apical] and [laminal] instead of the feature [±distributed], based on the observation that Australian languages show long-distance harmony patterns between laminals to which apicals are transparent, and vice versa. This point is not illustrated by Hamilton who states that "these patterns are at present poorly understood" (p. 42). The further distinction of laminals and apicals is undertaken by the four unary features [dental], [alveolar], [post-alveolar], and [alveolo-palatal] as Hamilton considers the use of the feature [±anterior] to be an overgeneralization (recall also the criticism on this feature in section 5.2.3.1). The complete specification with Hamilton's articulatory features (including additional features to distinguish labials and velars and for the tongue body shape) is given in (13) (from Hamilton 1996: 45).

[15] Hamilton refers to them as 'acoustic' features.

(13)	labials	[labial]
	lamino-dentals	[coronal], [laminal], [dental]
	apico-alveolars	[coronal], [apical], [alveolar]
	apico-post-alveolars	[coronal], [apical], [post-alveolar]
	lamino-alveolo-palatals	[coronal], [laminal], [alveolo-palatal], [high]
	dorso-velars	[dorsal], [velar], [high]

The reduplication problem occurring if both acoustic (see table 5.7) and articulatory features (see (13)) are assumed is solved by Hamilton by posing co-occurrence restrictions on the features. The acoustic feature [+flat], for example, is linked to the retroflex gestures, i.e. [coronal, apical, post-alveolar], because retroflexion is the only articulation which produces a [+flat] acoustic effect (p. 53). The co-occurrence restrictions are to be understood as phonetically grounded constraints (universally unviolated) to rule out impossible feature combinations such as [−flat] retroflexes or [+flat] non-retroflex coronals.

In general, Hamilton's dissertation convinces primarily because of its distinction between articulatory and perceptual representations and the proposal of complete feature systems to formalize both. Basing the articulatory features more on the actual dependencies of the articulators than was done before in FG (for instance, by treating apical and laminal classes as independent of each other, and by introducing separate place features for their dependents) is an important step forward towards more phonetically oriented representations. However, the work lacks an actual application of these features: no formal account of the phonotactic restrictions is given to illustrate the interaction of the features and the necessity of assuming these features.

5.3.3 Steriade: Licensing by Cue

A large part of Steriade's work (1995, 2001a, 2001b) deals with the two phonological processes of neutralization and assimilation and their phonetic motivation. The outputs of both processes are claimed to be determined by the distribution of the perceptual cues of input and output segment, not by their prosodic position. Her approach is termed 'licensing by cue', in contrast to the 'prosodic licensing' approach (Jun 1995, Beckman 1998, Lombardi 1999). Although Steriade applies her analysis to a large variety of processes (such as laryngeal neutralization, metathesis, and loan adaptation), the present discussion is restricted to the treatment of retroflexes for obvious reasons.

Neutralization of the contrast between apical alveolar and retroflex segments (as exemplified in section 4.5) has the same positional restrictions as the assimilation of retroflexes to apical alveolars (recall the examples in section 4.6): both processes take place mainly in post-consonantal and word-initial position. This similarity is explained by Steriade as being based on the non-available VC transitional cues in these positions. Let us take the cue distribution for retroflex stops as an example, which looks like the following, according to Steriade (1995: 16).

Table 5.8 Steriade's proposal for cue distribution in retroflex stops. This table combines the last two contexts into one column, whereas Steriade lists them separately, although they have the same cues. For possible differences, see text below.

contexts	V_V	V_C / V_#	#_V / C_V
cues	lowering of F3 + F4	lowering of F3 + F4	
	burst spectrum		burst spectrum
	burst amplitude		burst amplitude
	VOT		VOT
	closure duration		

This table shows that the intervocalic context (first column) provides the largest number of cues for retroflex stops and is therefore the context that provides most saliency. Although in the post-vocalic context (second column in table 5.9) there are fewer cues than in the pre-vocalic context (last column), these cues of lowered F3 and F4 are more salient than the prevocalic ones. Hence, retroflex segments can be distinguished best from other apicals in intervocalic position, quite well in postvocalic position (a point already illustrated in 3.3), and least in post-consonant or postpausal context. Besides context differences, the cue distribution also depends on the manner of segments (recall discussion in 3.3): fricatives, which have strong internal cues of frication noise, are less prone to assimilation and neutralization than stops. Nasals have weaker cues than both stops and fricatives, and often show assimilation or neutralization when the other two classes do not.

According to Steriade (2001a, 2001b), the speaker is aware of these distributions: in order to be able to assimilate or neutralize a retroflex segment, the speaker judges whether the modified output sequence would be perceptually very different from the expected output sequence. If this is the case, then assimilation or neutralization is prohibited. Only perceptually very similar pairs can undergo the processes. This awareness of cue distribution does not emerge from traditional phonological features. Steriade (2001a, 2001b) proposes a perceptibility map, or P-map, as a supplement to distinctive feature theory to provide this information. The P-map is defined as a "repository of speakers' knowledge […] that certain contrasts are more discriminable than others, and that the same contrast is more salient in some positions than in others" (2001a: 236). 'Contrast' in this definition refers to the perceived difference between two strings, the lexical norm and its potential modification, independent of its phonemic status. Sources for the knowledge represented by the P-map might be observations from confusion rates or similarity computations.

An example of a P-map is given in table 5.9 on the next page, where the font size reflects the similarity assumed between segments: the larger the font, the less similar the members of a pair.

Steriade, who works in an OT framework, links such a P-map to the grammar by correspondence constraints referring to the information given in the P-map. Thus, if a possible contrast x-y is perceptually more similar than the contrast w-z, then the correspondence constraint militating against a replacement of w by z is ranked higher than the one militating against a replacement of x by y.

Table 5.9 Hypothetical P-map fragment for apical pairs (Steriade 2001a: 237).

	V_V	V_#	V_C	#_V	C_V	C_C
s/ʂ	s/ʂ	s/ʂ	s/ʂ	s/ʂ	s/ʂ	s/ʂ
t/ʈ	t/ʈ	t/ʈ	t/ʈ	t/ʈ	t/ʈ	t/ʈ
n/ɳ	n/ɳ	n/ɳ	n/ɳ	n/ɳ	n/ɳ	n/ɳ

The contrast between apical alveolar and retroflex stop in a V_C context, for example, is more salient than the same contrast in a C_V context. Steriade formalizes this information as correspondence constraints which require identity of the feature [anterior], and their following ranking (Steriade 2001a: 240):

(14) IDENT (anterior) /V [_apical, stop] C >> IDENT (anterior) /C [_apical, stop] V

This ranking is assumed to be fixed (i.e., universal) and thus invariably predicts progressive assimilation for a sequence of retroflex–apical or apical–retroflex stops. Steriade (2001a: 241) points out that these constraints are highly specific, as they refer to specific values (anteriority) in specific segment types (apical stops) and specific contexts (V_C versus C_V).

Like Flemming's and Hamilton's accounts, Steriade's shows that phonological processes are sensitive to perceptual cues, and that it is necessary to incorporate these cues into phonological accounts. In contrast to the other authors discussed in this section, Steriade does not assume a perceptual specification of segments and therefore a separate set of perceptual features or cues. In her view, it is sufficient to introduce correspondence constraints that refer to the cue information stored somewhere else.

This latter point is exactly where Steriade's approach appears to be vulnerable to criticism. Two different devices are introduced to explain the influence of perceptual knowledge on phonological processes: the P-map and the correspondence constraints incorporating the information of the P-map into the grammar. Does the speaker really need a separate P-map, where the information is stored, when the same information could be integrated in the constraints and their rankings? The necessity for this duplication most likely emerges from the fact that the constraints used by Steriade refer to discrete phonological features, not to cues (no direct incorporation of perceptual knowledge). Looking at Steriade's constraints without the additional knowledge of the P-map, it does not become clear why exactly this ranking should be assumed as fixed, a point that she explicitly makes to justify the existence of the P-map.[16] However, direct reference to cue information and a strict division of

[16] Steriade (2001b: 2) writes: "The general rationale for the P-map proposal is that attested phonological systems display less diversity than predicted by versions of Optimality Theory (OT) in which correspondence and phonotactic constraints interact freely." Thus, the P-map is necessary to restrict constraint rankings and their possible outputs in Steriade's view. On the same page she comments that the non-restrictiveness of possible outcomes and repair strategies is not a problem of OT alone, and that other approaches also fail. This observation indicates that it might not be the framework that causes these problems, but the tools used within all these frameworks, namely the traditional, non-phonetically oriented features.

the constraints according to context could provide inherently ranked constraints and make an additional P-map superfluous. Instead of the feature [anterior], it is the transitional cue of F3 (and the burst noise) that differs between alveolar and retroflex apical stops and should therefore be made the argument of the IDENT constraints in (14). This supposes an underlying specification of segments by perceptual cues, which Steriade avoids. An alternative analysis of neutralization and assimilation of retroflex segments tackling this point is given in sections 6.3.5 and 6.3.6, respectively.

Another point of criticism of Steriade's work is that it exclusively focuses on some cues, while others are ignored. For example the distribution of cues depending on context in table 5.8 does not include any F3 (and F4) transitions of the retroflex into the following vowel. Steriade (2001a: 230) even claims that the second consonant in apical clusters "lacks all transitional cues to place distinguishing it from another apical." Section 3.5, however, illustrated that the CV transitions do differ for retroflex and apical alveolar. The burst spectrum in pre-vocalic position that is listed by Steriade (see last column in table 5.8), supplies another additional cue differentiating alveolars and retroflexes, although it is not put to use in Steriade's descriptions and analyses following her list.

A minor point on the notion of cue licensing has to be added. This term implies that any prosodic position is irrelevant for the distribution of cues, and thus the only relevant information for neutralization or assimilation of retroflexes is whether they occur in post-vocalic or post-consonantal position. Nevertheless, table 5.8 includes word boundary contexts. Furthermore, Steriade (1995: 17) states that the non-transitional cues (i.e. burst spectrum, amplitude and VOT) of the retroflex are stronger in initial position but she does not describe the consequences hereof for cue licensing. In later work, Steriade (2001a) mentions non-neutralization of word-initial retroflexes and calls it the 'initial deviation' (p. 226) as observable for instance in Djinang, which has an apical contrast word-initially but not post-consonantally (word-internal). In the same work, Steriade mentions that for neutralization processes a 'final deviation' occurs, where word-final apical segments are not assimilated to following word-initial apical segments but instead regressive assimilation applies (p. 227), for instance in Sanskrit and Punjabi. Steriade provides no explanation for these two deviations, and the different terminology used obscures the fact that both types of deviating behaviour save the cues of the word-initial position.

5.3.4 Boersma: Functional Phonology

In his theory of 'Functional Phonology (henceforth: FP), Boersma (1998, 1999) emphasizes the functional principles of efficient speech production, given here in (15).

(15) i. minimization of articulatory effort
ii. minimization of perceptual confusion

These two principles are already familiar to the reader from the description of Flemming's approach. Speech perception according to Boersma follows different functional principles, given in (16).

(16) i. maximization of recognition
ii. minimization of categorization

According to FP, the two different principles of speech production necessitate a distinction between articulatory and perceptual representations in phonology: articulatory effort, see (16i), refers to articulatory representations, and perceptual confusion, see (16ii), (plus the two perception principles in (16)) to perceptual ones. Furthermore, separate grammars are postulated to model production, perception, and recognition. Contrary to traditional views and Hamilton's and Flemming's approach, Boersma assumes the perceptual representation to be underlying. The perceptual UR is transformed into an articulatory output via the production grammar, see the first step in (17). This articulatory output is categorized by the listener (and the speaker, too) in the perception grammar into a perceptual form, see the second step in (17) (in Boersma's notation).

(17)

|underlying form|	→	[phonetic form]	→	/phonological form/
(discrete)	*production*	(continuous)	*perception*	(discrete)
perceptual specification		articulatory output		perceptual output

The production system of the speaker is modelled in FP as an OT production grammar as in (18) (1998: 146).

(18) FP production grammar

|*spec*|	A	B
[art_1] → /$perc_1$/	*!	
☞ [art_2] → /$perc_2$/		*

In this tableau, *spec* stands for the perceptual specification, art_x for candidates of the articulatory output, and $perc_x$ for corresponding perceptual outputs. Constraints applying in the production grammar are constraints for faithfulness of the perceptual output to the underlying perceptual specification (e.g. *REPLACE) and markedness constraints militating against complex/marked articulations (e.g. *GESTURE). "Low-ranked *GESTURE constraints determine the finite set of allowed articulatory features and feature combinations in one language" (p. 163).

A listener's categorization system can be similarly modelled by a perception grammar in an OT framework, see (19) (1998: 147).

(19) FP perception grammar

[*ac*]	A	B
/cat_1/	*!	
☞ /cat_2/		*

In the perception grammar model, *ac* denotes the acoustic input, and cat_x the candidate perceptual categories. The constraints relevant for the perception grammar are faithfulness constraints which militate against the warping of the existing perceptual categories in a language (*WARP) and markedness constraints against the perception of any category (*CATEG). As in the production grammar, low-ranked markedness constraints, here *CATEG, determine the finite set of allowed perceptual feature values. Features in this definition (and the above definition for the production grammar) are values on a continuous scale or combinations thereof. Feature values are given in concrete numbers, such as [260] (Hz) for a F1 frequency. According to faithfulness, listeners do not rank the acoustically realized feature values directly along continuous scales but categorize them into perceptual feature values (p.176).

Perceptual features are understood to be relatively independent from each other in FP, with hardly any hierarchical dependencies. An overview of these perceptual features and their dependencies is given in figure 5.4 (based on Boersma 1998: 23), where conjunction of features is shown by solid lines and disjunctions by dashed lines.

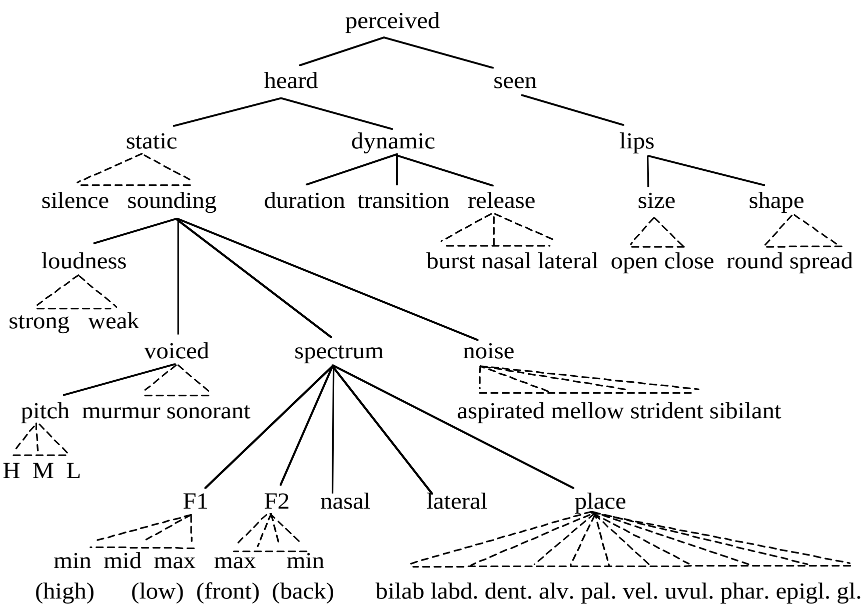


Figure 5.4 Perceptual features of FP and their dependencies.

The articulatory gestures used for the realization of the UR are not arranged in a hierarchy; Boersma argues that the articulators are nearly independent of each other. A representation of them is given in figure 5.5 on the next page (based on Boersma 1998: 23, figure 1.8).

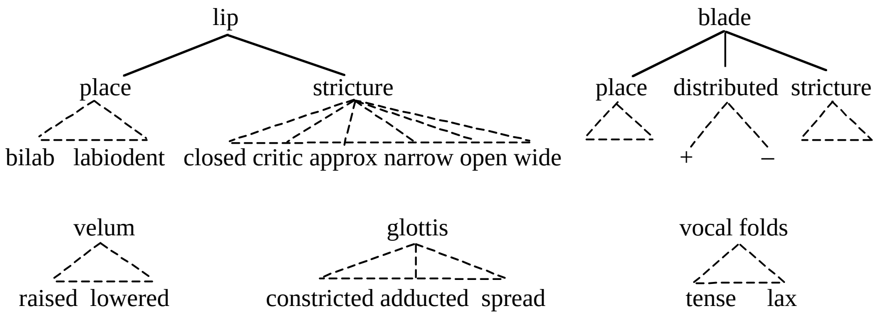


Figure 5.5 Articulatory gestures in FP.

Many of these gestural features have values along a continuous range, for instance the place feature for the tongue blade.

The notion of universality is interpreted in FP as the fact that languages tend to have similar phenomena because the communicative functions are similar in most languages. FP thus has no need for innateness. All features and representations can be learned without any previous knowledge since languages make use of the perceptual and articulatory possibilities.

To summarize, the theory of FP makes some assumptions that depart radically from traditional featural theories. First of all, both articulatory and perceptual features are necessary, with perceptual ones as underlying specifications. Secondly, the features are not innate, and thus the feature values chosen from articulatory and perceptual space are not universally valid but are language-specific. Thirdly, features are not used to define cross-linguistic categories. These points tackle exactly the problems with FG and its modifications as pointed out above.

A point not fully developed in Boersma's FP is the system of articulatory gestures as depicted in figure 5.5. For articulations with the tongue, only 'blade' is explicitly given and further specified with 'place', 'distributed', and 'stricture'. The use of the subspecification 'distributed' is not defined, but can be assumed to follow traditional definitions, where the tip and the blade are subsumed under one node and are distinguished by [±distributed]. Thus, the tip and the blade of the tongue are treated as being depend on each other in Boersma's model. Besides giving the exact articulator, a gestural model also needs to take into account the restrictions on the co-occurrence of tongue gestures, a point that is not included in FP. The interaction of tongue gestures will be further illustrated in section 5.4.2.

Boersma does not explicitly deal with any phonological processes involving retroflexes. The application of FP to retroflex processes with modifications newly introduced here will be described in section 5.4 below and demonstrated in greater detail in chapter 6.

5.4 Featural representation of retroflexes: Present approach

Following the proposals made by Flemming, Hamilton, and Boersma described above, my own proposal also involves perceptual features in addition to articulatory ones in order to capture all phonological processes of retroflexes discussed in chapter 4. Both perceptual cues and articulatory gestures are necessary for phonological representations because of their different functions (in line with Flemming 1995 and Boersma 1998): perceptual features are responsible for acquisition (see Boersma 2000),[17] articulatory ones for assimilation processes (see the traditional featural accounts and Browman & Goldstein 1989, 1992). This poses the problem of duplicating information by having both articulatory and perceptual features. In contrast to Flemming, I assume that the perceptual features do not emerge from underlying articulatory representations that are mapped onto auditory representations. Hamilton's proposal to restrict perceptual features by co-occurrence constraints is also not followed here. Instead, I adopt Boersma's idea of underlying perceptual representations, which are mapped onto articulatory gestures via a production grammar.

As illustrated in section 5.1 in general and in section 5.2.3.3 for FG specifically, traditional feature approaches assume three functions of phonological features: describing natural classes, yielding a tool to describe the phonological processes in a given language, and ensuring phonetic interpretability. These three functions were shown to be in conflict, since the description of natural classes requires a minimal, abstract set of features, whereas phonetic interpretability and the description of phonological processes in specific languages requires fine-grained, phonetically based features. These different tasks should be performed by different sets of features, as illustrated in (20).

(20)	*function*	*feature set needed*
(a)	representation & phonetic interpretability	language-specific sets of phonetically based features
(b)	classification	abstract, universally valid class features

Returning to the example of the feature [voice] from section 5.1, this feature is a very abstract means for cross-linguistic classification, see (20b). Single languages such as Dutch or German instead use the phonetically interpretable features [vocal fold vibration] and [aspiration], respectively, see (20a). Phonological descriptions of single languages thus require language-specific sets of features, which are based on the phonetic realizations of the segment classes in the languages. My primary goal here will be to explicate my views on the former set of features (20a) since I consider this closer to the central aim of phonology, slightly neglecting the latter set (20b) in the following discussions.

A feature set fulfilling the functions under (20a) has to be very close to phonetics, i.e., has to be directly phonetically interpretable. This can be realized by taking phonetic cues as the prime elements of phonology instead of whole segments (as

[17] Acquisition processes include sound change. See Ohala (1989, 1993) for an illustration of the relevance of perceptual cues in sound change.

in a phonemics or segmentalism approach) or so-called universal features which cannot be directly interpreted (as in traditional feature geometry). The approach taken here is as illustrated in figure 5.2 above, repeated here in figure 5.6 for convenience.

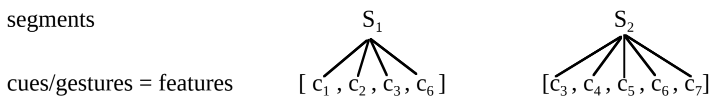


Figure 5.6 Schematic representation of relation segment – cues in phonetic approaches.

According to this view, the phonetic cues, i.e. the features, are directly phonetically interpretable. Figure 5.6 is slightly simplified as it implies that only single cues can be features, a point that is certainly not valid: it is often not only one cue but cue clusters which are the trigger or the target of specific phonological processes. Furthermore, not all cues of a segment class are used as phonologically distinctive cues in a language. Thus, an intermediate level in our model of the connection between segments and phonetic correlates can be posited in which only those cues and cue clusters are stated that are relevant to the phonology of the language in question. This yields the following model:

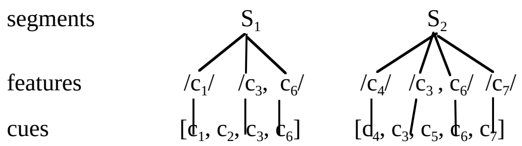


Figure 5.7 Schematic representation of phonetic features.

It might be asked where the difference lies between traditional features as depicted in figure 5.1 and the phonetically-based features postulated here, see figure 5.7, because the former are also correlated with phonetic cues and are an intermediate level between segments and these cues. But whereas traditional phonological features are mainly binary, are derived from cross-linguistic observations and are not directly phonetically interpretable, the present phonological features can be scalar, directly interpreted, and are language-specific. The phonological representations assumed here are therefore rich.

As phonetic cues and gestures are based on the articulatory and perceptual systems of humans, they can be assumed to be universally restricted, in as far as no gesture or cue occurs in any language that is articulatorily impossible or not perceivable. In this sense, phonetic cues and gestures make up a universal set from which languages make use. A difference between important and non-important features or primary and enhancing features as proposed for instance by Stevens et al. (1986) therefore cannot be stated as universal since the possible set of enhancing features totally depends on the features each language choses as primary.

In figure 5.7, I deliberately refer only to cues, that is, perceptual cues, in the lowest level of representation since I assume that perceptual cues are the primary correlates and the basis for phonological features from which articulatory gestures are derived. Underlying representations are therefore assumed to be perceptual, following Boersma (1998, 2001). The transformation of this underlying perceptual representation into an articulatory representation is performed in the production grammar of the speaker (again following Boersma); only the perceptual representation is stored in the mental lexicon. An illustration of the assumed model is given in figure 5.8 (based on Boersma 1998: 143), see also (17) above.

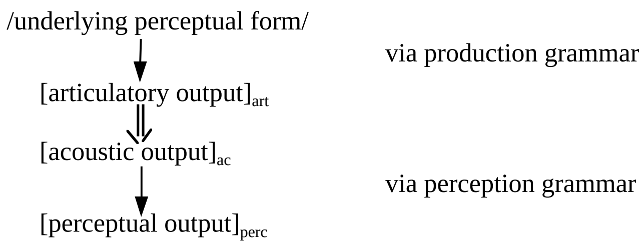


Figure 5.8 Correlation between underlying perceptual representation and articulatory representation according to Boersma's model for a speaker, with separate production and perception grammar.

The details of the perceptual and articulatory representations in my account are explained in the following subsections.

5.4.1 Perceptual representations

The perceptual representation proposed here does not consist of a complete set of features. Instead, only those features are illustrated that are relevant and sufficient for the analysis of retroflexes in chapter 6. Suggestions for other features are given where possible. Cues for voicing, implosion, and ejective articulations are ignored here. The representations are labelled "perceptual", although as illustrated in chapter 3, they are actually acoustic characteristics. The label perceptual is used to indicate that it is the perception of the information by the listener which is relevant, not the way we technically measure and describe this information.

The perceptual features assumed here are in line with Boersma's proposal (see figure 5.4): they project their own tiers, and are hierarchically independent of each other. In contrast to Boersma, the perceptual representations applied here are phonetically rich. Instead of actual values for the different features, I will use a stylized ordering representation, similar to that of Flemming (2002): formant frequencies are represented by 5 to 9 values. This step of abstraction is taken because I am dealing with data from several languages and several speakers, where the actual values are expected to differ from language to language. The abstraction with several values is made for ease of comparison. In contrast to Flemming, who uses the values 1 to 5, I term the lowest formant value maximally [–4], the middle value [0], and the highest formant value maximally [+4], to facilitate an interpretation as low, middle, and high formants.[18] The zero value should not be mistaken as an indication that no formant is present. The absence of a feature is not specified in my approach. The absence of formant frequencies and frication noise in the case of stop closures, however, is specified with the cue [silence] since this is a relevant cue for the identification of the stop manner. Furthermore, the duration of a stop closure is an additional feature to specific places of articulation (recall the difference between very short stop closures in retroflexes and rather long stop closures in laminals in section 3.3.3), and it indicates the difference between geminate and singleton segment. Possible values for this feature are [0] for an average closure length as in laterals, [–1] for short closures as found in retroflexes, [+1] for long closures as in laminals, and [+2] and higher for geminate segments.[19]

Segment classes with inherent formants (e.g. nasals, laterals, and rhotics) can be presented with values for the features F2 and F3 (as explained in section 3.1, F1 is not used here for differentiating consonants). The same features will be used for the representation of stops, since they have formant transitions leading into and out of the stop closure. Furthermore, I will describe fricatives by F3 values, which stand for the lowest peak in the friction noise (see section 3.3.2). By this rather abstract representation, I yield the same features for retroflex articulations across all manners.

Based on the formant values as described in section 3.3.1, the following values are assigned for consonants:

Table 5.10 Values for the formant features [F2] and [F3] for consonants.

	labial	laminal dental	apical alveolar	laminal pal.alv.	retroflex	velar
[F2]	0	+1	+1	+2	+1	–2
[F3]	–1	0	0	+2	–2	–1

The class of coronals is roughly captured by high [F2] values, and a retroflex class with the feature specifications [+1F2] and [–2F3]. Not all retroflexes have a subapical post-alveolar articulation, as we saw in chapter 2. Retroflex segments with an apical post-alveolar constriction instead of a subapical one, which was explained to result in a higher F3 than in the average retroflex in chapter 3, are represented with the feature value [–1F3] (as for instance for the segments in the West-African language Ewe).

Vowels are represented by the features [F1] and [F2] as illustrated in table 5.11 and 5.12. The [F2] features are conditional on [F1], e.g., [+4] refers to a different

[18] In an earlier account (Hamann 2002b), I used binary features (comparable to those used by Flemming 1995). This approach is not followed here, as it necessitates describing a linear scale of three and more values with several binary features.

[19] Certainly the length of a geminate depends on the length of its singleton counterparts and also on the length of the preceding vowels; thus, a more fine-grained value system is necessary to account for this variation. As my analysis in chapter 6 involves no geminates, a further refinement is not needed here.

actual F2 value for [i] than for [e]. Rounding makes a difference of 2 values for [F2], and place a difference of 3 values.

Table 5.11 Feature [F1] with its values for low to high vowels.

[F1]	+3	+2	+1	0	–1	–2	–3
	a	æ	ɛ, ɔ	ə	e, o, ø, ɘ, ɤ	ɪ, ʊ	i, u, ɨ, ʉ, ɯ, y

Table 5.12 Feature [F2] with its values for front to back vowels (including the influence of rounding).

[F2]	+4	+3	+2	+1	0	–1	–2	–3	–4
unrounded	i, e, ɛ			ɨ, ɘ		ʉ	ɯ, ɤ		
rounded			y, ø						o, ɔ, u

In addition, rounded vowels are specified by a low F3, i.e. [–2F3] (according to Stevens 1998: 292ff., rounding results in a prominent, low F2-F3 peak for vowels).

Besides the formant structures, consonants are also specified by manner-specific features such as friction noise, burst noise, and so on. These features and their values do not have to be specified for the analyses in chapter 6, but could be formalized easily: friction noise, for instance, can be represented as in Flemming's noise frequency scale (recall (9b)).

Reference to these perceptual features in the FP version of OT used here is made by specific constraints, as will be elaborated in section 6.1.

5.4.2 Articulatory representations

The independent articulatory gestures of the Boersma model as illustrated in figure 5.5 are adopted here as articulatory representations. The interaction of these gestures can be modelled as in Browman & Goldstein's (1989) Articulatory Phonology, in which each gesture is assigned a single tier, and where the duration and overlap of gestures is represented by overlap of the gesture tiers on a temporal axis. Some minor modifications are introduced here to Boersma's gestures. In addition to the specification of non-tongue articulations, the present model includes four separate representations for the tongue parts, namely tip, blade, middle, and back. All four of them can be further specified by the stricture type and the exact place of articulation. Boersma's specification 'distributed' for the feature blade is not taken over here.The resulting representations for the tongue parts is illustrated in figure 5.9 on the next page.

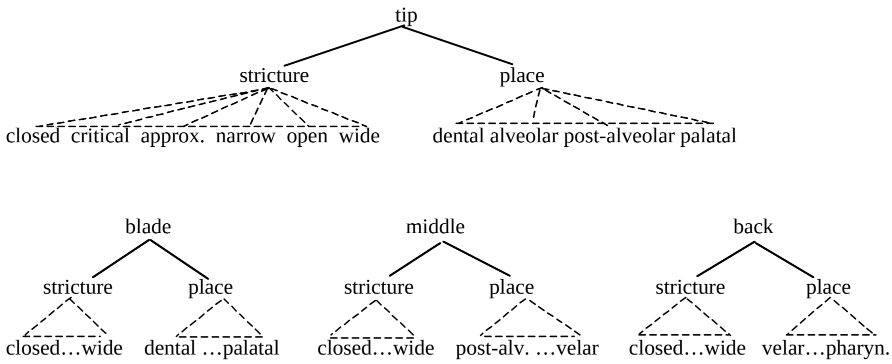
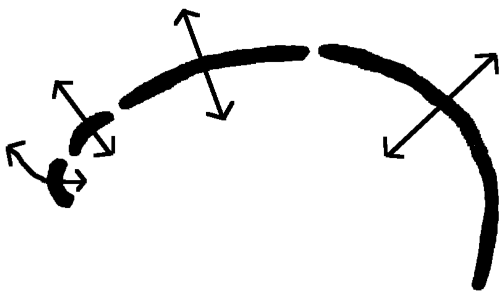


Figure 5.9 Articulatory gestures of the tongue.

The proposed tongue parts and their possible movements are depicted in figure 5.10, in which only the tongue surface is shown.



tip – blade – middle – back

Figure 5.10 Abstract assumption on tongue parts and their movements on the vertical axis.

This figure is a simplification of the possible tongue tip movements in the vertical, i.e. the height, dimension. The subdivision proposed here departs from the FG classification of the tongue into coronal and dorsal features in as far as it gives independent status to apical and laminal articulation (they are not united under a node such as CORONAL), and provides a further subdivision of the dorsal tongue part into tongue middle and back, again both not dependent of one node. Evidence for this division is the observation that these four articulators are independently involved in the major articulations of the tongue. In section 5.2.3.2 on the attempts within FG to describe the tongue dorsum movements, we saw that two kinds of movements have to be distinguished, namely a raising or lowering of the tongue middle and a retraction or fronting of the tongue back, usually represented by the DORSAL features [high] and [back]. The problems with this representation and proposed alternatives were described in the same section.

The presentation proposed here avoids a further problem encountered within FG: the drawing of a borderline between coronal and dorsal articulations. The post-alveolar, alveolo-palatal, and palatal articulations, which were all described as phonetically and phonologically involving both coronal and dorsal articulations (recall the discussion in section 5.2.3.3), now belong to the articulation with the tongue middle (part of the former DORSAL), which are shown below to trigger co-articulation of the tongue blade (part of the former CORONAL).

The four tongue articulators can move either upwards or downwards from their rest-position (as illustrated in figure 5.10), yielding the following articulations:

(21)	tip	up	apical alveolar articulations
		down	withdrawn tongue tip (e.g. for laminal post-alveolars)
	blade	up	laminal post-alveolar articulations
		down	lowered and stretched tongue blade (e.g. for apical post-alveolar articulations)
	middle	up	palatal articulations
		down	lowered tongue middle (e.g. for velar articulations)
	back	up	velar articulations
		down	tongue fronting (e.g. for palatal articulations)

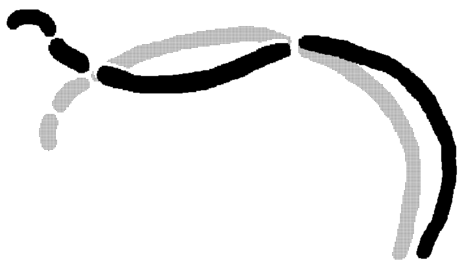
This list does not include movements in the horizontal axis. Every tongue part can move backwards and forwards if it is up, i.e., fronting or backing can occur. These possibilities are elaborated in (22). The downward movements have only limited options of displacement, which are therefore omitted here.[20]

(22)	tip	fronted	apical dental articulations
		backed	apical post-alveolar to palatal articulations
	blade	fronted	laminal dental to alveolar articulations
		backed	laminal post-alveolar to palatal articulations
	middle	fronted	alveolo-palatal articulations
		backed	velar articulations
	back	fronted	velar articulations
		backed	pharyngeal articulations

This list of the fronting and backing movements of the tongue parts and that of the raising and lowering movements in (21) indicate that the single tongue articulations are not independent of each other: gestures involving the movement of one part of the tongue always affect adjacent parts. Apical articulations cause the laminal area to move, laminal articulations raise the apex and the tongue middle, and movements of the tongue back cause a lowering of the tongue middle. Furthermore, certain chain reactions can occur. The displacement of the tongue tip to the post-alveolar region or further back (i.e. retroflexion) causes the tongue middle to lower and the

[20] Both the backing of the tongue middle and fronting of the tongue back are assumed to result in a velar articulation. This is due to the fact that horizontal displacements of the tongue body are rather restricted and do not seem to result in several articulatory classes.

tongue back to rise. A graphic illustration of this is given in figure 5.11. The underlying grey line shows the tongue parts at position of rest, as in figure 5.10.



tip – blade – middle – back

Figure 5.11 Retroflexion of the tongue tip and concomitant movements of the whole tongue.

The restrictions on the co-occurrence of the tongue movements as given in (21) and (22) have to be formalized explicitly; they cannot be expressed by grouping the respective tongue parts under a common node as assumed in FG. My formalization of these interactions as articulatory implications together with constraints on the articulatory gestures introduced here is given in section 6.2 below.

5.5 Conclusion

It was shown in this chapter that the traditionally assumed three functions of phonological features are incongruous: distinguishing natural classes is at cross-purposes with attempts to account for phonological processes and securing phonetic interpretability. These functions have to be distinguished and realized by two distinct devices, one that is adaptable to language-specific phonetics and phonology, and another, more abstract, one that can be used for the paralinguistic task of classification.

Connected with the functional restriction of features, it was proposed in the present model that features are not innate. The main evidence for innateness of features is the existence of identical phonological processes and segment classes in unrelated languages that are accounted for in traditional approaches by ‘natural’ classes sharing the same feature. Thus it is traditionally assumed that retroflexes are a natural class due to their innate, shared features [CORONAL, –anterior, –distributed]. This class is argued here to emerge, however, via similar (not necessarily identical) ways of articulation as described in chapter 2, and via their perceptual similarity, as described in chapter 3. The similar phonological behaviour of these segments as illustrated in chapter 4 is therefore grounded in their similar phonetic properties (articulatory gestures and perceptual cues), and is not a result of their sharing the same universal features.

Lastly, it was argued that phonological processes involve both articulatory and perceptual information, and therefore both articulatory and perceptual representations are necessary in phonology. Instead of the traditionally assumed underlying articulatory specification, the present approach assumes an underlying perceptual presentation from which the articulation is derived, as illustrated in figure 5.12.

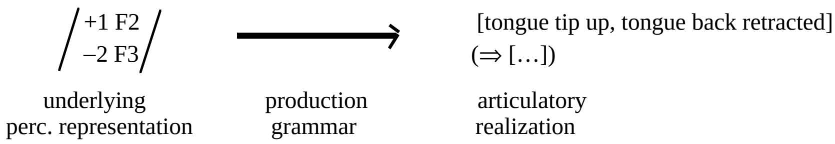


Figure 5.12 Representation of the perceptual UR of retroflexes and their realization in the articulation grammar by specific gestures (which imply other gestures, as illustrated in section 6.2 below), according to the model of FP applied here.

The perceptual features given on the left of figure 5.12 are only a very reduced set, and are not meant to be a full specification, as already discussed in chapter 3. Furthermore, they are generalized across the languages discussed, in order to yield a tool to describe all retroflexes in these languages similarly. However, the representations actually needed for the phonological description of a single language may look different according to the inventory and processes found in this language. For the case of the two retroflex fricatives in Toda, for instance, the apical post-alveolar may be specified as [+1F2, –1F3], and the subapical palatal as [+1F2, –2F3]. Thus the non-innate perceptual UR proposed here can avoid the problem of distinguishing these two classes encountered in FG.

The articulatory representation on the righthand side of figure 5.12 and its implication of other gestures will be further specified in chapter 6.2. Both the underlying perceptual representation of retroflexes, and the articulatory gestures associated with it, are put to use in the following chapter.

6 Analysis of retroflex processes

The aim of the present chapter is to provide analyses in an OT framework (Prince & Smolensky 1993) for the diachronic and synchronic segmental changes described in chapter 4, which are caused by a retroflex context or which result in retroflexion or de-retroflexion. One exception to this general aim exists: this chapter does not account for processes that were attributed to misparsing errors of listeners only. Since no articulatory gestures are saved via such a misparsing process, no articulatory optimisation strategies apply, and therefore misparsing has no functional motivation in production. An analysis of a misparsing error in a functionally based OT production grammar is thus impossible. In chapter 4 a reassociation of cues was proposed as an alternative explanation for, for instance, a change from alveolar to retroflex in a back vowel context or a change from a high front vowel to a rounded high front vowel in a retroflex context. There I also illustrated the acoustic similarities between the original forms and the forms the listener derived from reassociation of cues. An OT formalization of these processes needs to be modelled in a perception grammar but this would be outside the scope of this book. Only one process below will include a formalization of a perception grammar, namely secondary palatalization of retroflexes in section 6.3.3.5. In that section, both production and perception grammar are modelled to illustrate that the gestural sequence of a retroflex and a palatal glide can be perceived as a secondarily palatalized retroflex.

This chapter is structured in the following way. Section 6.1 introduces the constraints on the perceptual specifications used here, section 6.2 deals with the constraints on the articulation, section 6.3 provides analyses for the processes discussed in chapter 4, and section 6.4 concludes. Together, these sections provide phonological accounts for the processes illustrated in chapter 4. Furthermore, cross-linguistic variation that could be found for some processes will be accounted for, either by phonetically motivated universal rankings of articulatory markedness constraints and language-specific rankings of faithfulness constraints, as in the case of vowel retraction and lowering (section 6.3.3.2), or by faithfulness constraints that are universally ranked plus language-dependent rankings of articulatory markedness constraints, as in the case of context-sensitive assimilation processes (section 6.3.6).

6.1 Constraints on perceptual representations

For the analysis of processes involving retroflexes, I assume underlying perceptual specifications as illustrated in section 5.4.1 above. Departing from Boersma (1998, 1999, 2003a, b), the perceptual specifications are represented as underlying representations or inputs in a traditional slashed line notation, such as /i/ for a high front vowel. The perceptual URs are associated with articulatory gestures that implement these specifications. Every output candidate to be evaluated is thus a pair of perceptual features correlated with articulatory gestures (Boersma 1998: 146): [art_1] /$perc_1$/. Boersma's notation does not list all the articulatory gestures and perceptual features present in a segment, but gives shorthands using the easily interpretable IPA symbols. The present exposition proceeds similarly. Furthermore, in the present analysis the output pairs [art_1] /$perc_1$/ are further abbreviated to one form, the traditionally used IPA transcription in square brackets, such as [i]. It has to be kept in mind, though, that this stands for a candidate output form with both articulatory and perceptual specifications.

Due to my assumption that underlying specifications are perceptual, faithfulness constraints (henceforth: faith constraints) only hold for the perceptual representations of items. Being faithful to an articulation is hence not possible, contrary to what is assumed in standard versions of OT (McCarthy & Prince 1993, 1995; Prince & Smolensky 1993). Three constraint families ensuring the faithfulness to features or segment content are distinguished here: *DELETE, *INSERT, and *REPLACE, following Boersma (1998). A further constraint family preventing the change in timing of two adjacent features or segments is used, namely the PATH constraints (Boersma 1998: 193f.).

*DELETE constraints militate against the deletion of underlying perceptual features, and are similar to McCarthy & Prince's (1995) IDENT. The *DELETE constraint family can prohibit deletion of single features, see for example (1a) and (1b).

(1) (a) *DELETE (+1F2): "Don't delete the underlyingly specified feature [+1F2]."
(b) *DELETE (–2F3): "Don't delete the underlyingly specified feature [–2F3]."

Faithfulness to the combinations of features in a segment can be described by constraint conjunction. If a language has retroflex segments, for example, the two features [+1F2] and [–2F3] cooccur to form the class of 'retroflex'. Deletion of a retroflex segment violates a conjoint constraint as defined in (2a). In (2b) – (2d) constraints are formulated militating against feature combinations that determine specific manners of articulation (in a shorthand notation instead of listing all the cues for stops, fricatives, approximants, and so on, in detail). (2e) illustrates a constraint preserving combinations of features for manner and place.

(2) (a) *DELETE (+1F2 & –2F3): "Don't delete both underlyingly specified features [+1F2] and [–2F3] (i.e. a retroflex)."
(b) *DELETE (stop): "Don't delete the underlyingly specified stop features (silence, burst, etc.)."
(c) *DELETE (rhotic): "Don't delete the underlyingly specified rhotic features (formant weakening, etc.)."
(d) *DELETE (fricative): "Don't delete the underlyingly specified fricative features (friction noise, intensity, etc.)."
(e) *DELETE (ʈ ɖ): "Don't delete the underlyingly specified retroflex stop features."

Naturally, we can assume that faith constraints applying to one feature only are violated far more often than those for feature combinations, since the deletion of one feature is perceptually more tolerable than the deletion of several features.

We can see from the examples in (1) and (2) that the faith constraints can target three different types of arguments: single features as in (1a) and (1b); feature combinations for describing natural classes, which are usually given with shorthand notations and not with all features listed, such as (2b) – (2d); or thirdly feature combinations that describe specific segment classes, e.g. (2e) which targets the group of retroflex plosives. The last type of argument is notated with IPA symbols.

If only one feature is deleted, inserted, or changed, Boersma's constraints correspond to McCarthy & Prince's (1995) IDENT constraint, which militates against changes of single features,[1] If feature combinations making up a whole segment are deleted, inserted, or changed, the corresponding constraints in McCarthy & Prince's framework are Max-IO against deletion, DEP-IO against insertion, and both against segmental changes.

The second type of faith constraints used here are *INSERT constraints, which prohibit the insertion of surface features or feature clusters. *INSERT constraints are defined analogously to the *DELETE constraints. Examples are given where needed in the analysis below.

The third type of faith constraint used for the present analysis is the *REPLACE constraint family, which accounts for changes of one feature value into another value on the same perceptual tier. *REPLACE constraints depart from McCarthy & Prince's approach, where a process of feature change is formalized as violation of an IDENT constraint. What IDENT fails to capture is the possibility of gradual changes in feature-values, and the fact that a small change is better accepted (i.e. causes fewer constraint violations) than the deletion of a whole feature and the insertion of a new one. A definition of *REPLACE is given in (3), from Boersma (1998: 176f.).

(3) *REPLACE (*feature*: *value*$_1$, *value*$_2$ */ condition / left-env_right-env*):
"Do not replace a specified value (*value*$_1$) on a perceptual tier (*feature*) with a different value (*value*$_2$), under a certain *condition* and in the environment *left-env* and *right-env*."

Examples of universally ranked, gradient *REPLACE constraints that are sensitive to the context will be given in section 6.3.6 below.

Faithfulness to the underlying simultaneity or non-simultaneity of features will be expressed in terms of PATH constraints (Boersma 1998: 193f., based on Archangeli & Pulleyblank 1994). *INSERTPATH as defined in (4) militates against the insertion of a path between two features that was not specified in the underlying representation, see the definition in (4) (from Boersma 1998: 194).

(4) *INSERTPATH ($f \times g$): "A combined feature on the tiers *f* and *g* that is heard in the surface form, also occurs in the specification."

[1] Zoll (1996) subdivides McCarthy & Prince's (1995) IDENT constraint into MAX [F] and DEP [F], analogous to MAX-IO and DEP-IO.

Outputs violating *INSERTPATH constraints create a simultaneity of two features that was not present in the underlying representation.

*DELETEPATH constraints as defined in (5) (also Boersma 1998: 194) militate against the deletion of a path, which results in non-simultaneity of the underlyingly simultaneous features involved.

(5) *DELETEPATH ($f \times g$): "A specified combined feature on the tiers *f* and *g* appears (is heard) in the surface form."

Specific PATH constraints needed for the present analysis will be defined below when necessary.

6.2 Constraints on articulatory representations

Before defining the necessary constraints on the articulatory representations, we have to go back to the model of independent tongue parts introduced in 5.4.2, repeated here in figure 6.1, because it has consequences for possible articulations and therefore restricts our articulatory representations of segments.

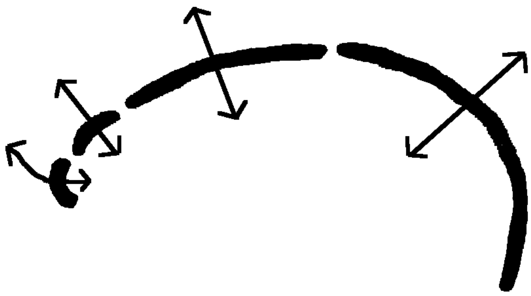


Figure 6.1 Abstract assumption on tongue parts and their movements on the vertical axis.

This model divides the tongue into four parts, the tip, blade, middle, and back (including the root), with borders as defined in chapter 2. Contrary to distinctions of the tongue in other models, for instance the coronal – dorsal distinction in FG as described in chapter 5, the present model does not assume that the separate tongue parts can act independently of each other. The four parts can separately be the active articulator in producing the restriction relevant for specific articulatory classes, but the movement of one part triggers certain movements of adjacent and even non-adjacent parts. This was illustrated in chapter 5. The raising of the tongue blade, for example, was shown to cause the tongue middle to rise as well, though not to the same extent as an active constriction of the tongue middle would. Restrictions on adjacent tongue parts can be expressed formally as in (6), which is not a complete list.

(6) (a) *[tongue blade up, tongue middle down]
(b) *[tongue blade down, tongue middle up]

(c) *[tongue middle down, tongue back down]
(d) *[tongue middle up, tongue back up]

These restrictions are not active cooccurrence constraints (such as proposed for example by Calabrese 1988 or Hamilton 1996), as they need not be present in the phonology of the speaker. Instead, these statements express physical restrictions on the vocal apparatus, and formalize what is impossible to articulate. They restrict the number of possible output candidates (thus are part of Gen in traditional OT terms), as outputs can only be producible articulations (Boersma 1998: 278).

For complex articulations such as retroflex segments, the articulatory restrictions can be understood as some chain implication, as formalized in (7a).

(7) (a) [tongue tip up & back] → [tongue blade front & displaced], [tongue middle down], [tongue back up]
(b) [tongue blade up] → [tongue middle up], [tongue back down]

The interaction of the tongue parts for retroflex articulation as given in (7a) can account for several phonological restrictions of retroflexes as illustrated in sections 6.3.1 until 6.3.6.

It is important to note that the division of the tongue into parts and their interplay as assumed here is not exclusively designed for modelling retroflex articulations. (7b) gives the interactions of tongue parts for a laminal articulation: here the raising of the laminal area causes a concomitant raising of the tongue middle. This correlation can be found in phonetic accounts of laminals, which are often described as slightly palatalized. Furthermore, it can account for the fact that laminal but not apical stops show additional affrication: due to the raising of the tongue middle, laminals have a long area of constriction behind the closure, which promotes affrication in stop release.[2]

After clarifying these articulatory correlations and their restrictions on the vocal apparatus, we can now move on to the articulatory constraints necessary for our representations. Restrictions on articulation hold only for the articulatory form, and are therefore formulated as markedness constraints on the articulatory part of output. General restrictions on the effort of producing an articulation (described for instance by LAZY by Kirchner 1997) are further distinguished here into *GESTURE, *DISTANCE, *SYNCHRONIZE and *PRECISION constraints.

The first type of articulatory constraint described here is the *GESTURE constraint family as developed by Boersma (1998: 152). For our purpose, we need the following *GESTURE constraints:

(8) (a) *GESTURE (tongue tip: neutral to post-alveolar) = *GESTURE (retroflex): "do not articulate a retroflex segment."

[2] Kehrein (2002: 60f.) describes the correlation of laminality and affrication and ascribes it to the displacement and slowness of laminal articulations. Laminal articulations, however, are not by default displaced: laminal post-alveolars for example involve only a raising of the tongue blade but no displacement (recall section 5.4.2). Furthermore, it is not clear how the slowness of laminal gestures can account for the occurring affrication. The explanation proposed here with cooccurring tongue middle raising thus seems superior to the one given by Kehrein.

(b) *GESTURE (tongue tip: neutral to alveolar) = *GESTURE (apical alveolar): "do not articulate an apical dental or alveolar segment."
(c) *GESTURE (tongue back: neutral to retracted) = *GESTURE (retraction): "do not articulate a segment with a retracted tongue back."

The constraints in (8a–c) militate against specific articulatory classes, namely retroflexes, apical alveolar/dentals, and secondary articulations such as retraction for non-retroflex segments. If a language has retroflex segments, the constraint (8a) is very low ranked. If a language has an apical but no retroflex series, the constraints are ranked as *GESTURE (retroflex) >> *GESTURE (apical alveolar).

In addition to the constraints against the articulation of specific classes in (8), further constraints on articulation are needed that can account for the reluctance of the articulators to change their position from one gesture to another. Boersma's (1998: 150) *DISTANCE constraint family seems to meet this purpose, see (9), where | stands for an articulatory contour, i.e. a change in position (or tension) of the articulator.

(9) *DISTANCE (*articulator: a | b*): "An *articulator* does not move from location *a* to *b*, away from the neutral position."

For our purposes, we need specific *DISTANCE constraints as defined in (10).

(10) (a) *DISTANCE (tongue tip: retroflex | alveolar) = *DISTANCE (tip): "The tongue tip does not move from location post-alveolar to alveolar and vice versa."
(b) *DISTANCE (tongue back: retracted | fronted) = *DISTANCE (back): "The tongue back does not move from location retracted to fronted and vice versa."
(c) *DISTANCE (tongue tip: $manner_1$ | $manner_2$) = *DISTANCE (manner): "The tongue tip does not move from location $manner_1$ to $manner_2$ (e.g. from approximant to full closure)."

(10a) and (10b) militate against changes in place of articulation, whereas (10c) avoids a change in apical manner. Constraint (10b), which disallows a change in tongue back position, also militates against a change from flat tongue middle to high tongue middle by the articulatory restrictions on tongue movements elaborated above. It applies to all retroflex articulations due to the correlation stated in (7a) above.

A universal ranking of a specific *DISTANCE constraint family and its relevance for language-specific variation will be illustrated in section 6.3.3.2 below on vowel retraction and vowel lowering.

Besides *GESTURE and *DISTANCE, a third type of articulatory constraint family, namely *SYNC, is required for our analysis. *SYNC constraints describe the unwillingness of two gestures on different tiers to exactly finish the first gesture when the second starts. A general definition is given in (11) (Boersma 1998: 154).

(11) *SYNC (*articulator*$_1$: *from*$_1$ | *to*$_1$; *articulator*$_2$: *from*$_2$ | *to*$_2$): "the movement of *articulator*$_1$ from *from*$_1$ to *to*$_1$ is not synchronous with the movement of *articulator*$_2$ from *from*$_2$ to *to*$_2$."

The articulatory result of this constraint might be either an overlap or a delay between two gestures. For describing sequences of front vowels and retroflex consonants and the gestural overlap to be observed there, we need the following *SYNC constraint:

(12) *SYNC (tongue middle: raised | lowered; tongue tip: neutral | closed) = *SYNC (vowel| retroflex): "the lowering of the tongue middle (for the vowel) is not synchronized with the closure of the tongue tip (for the retroflex)."

A synchronization of the articulatory gestures is not specified in the underlying, perceptual representation. It can only be achieved by being faithful to the synchronization of the perceptual features, as stated in the PATH constraints in (4) and (5). Non-synchronization of gestures is therefore accepted as long as it does not result in a shift of the perceptual features.

A last articulatory constraint family that will be needed for the present analysis is *PRECISION as formulated in (13) (Boersma 1998: 155).

(13) *PRECISION (*articulator: position | environment*): "In a certain *environment*, a certain *articulator* does not work up the precision to put itself in a certain *position*."

This constraint family can account for the fact that some manner classes have to be articulated more precise than others. A trill, for instance, requires a more precise gesture than a flap, thus the following ranking holds:

(14) *PRECISION (trill) >> *PRECISION (flap)

6.3 Analysis of phonological processes of retroflexes

With the constraints restricting perceptual and articulatory specification in place, we can now formalize the patterning of the phenomena of retroflexion as illustrated in chapter 4, repeated here in (15) for convenience.

(15)

	input	*output*	*process*
(a)	/rt/	[ʈ]	retroflexion in rhotic context
(b)	/ut/	[uʈ]	retroflexion in back vowel context
(c)	/iʈ/	[it] or [ɨʈ]	deretroflexion or vowel retraction
	/ʈʲ/	[tʲ] or [ʈ]	deretroflexion or depalatalization
(d)	/Vʈ/	[V˞ʈ]	retroflexion of adjacent vowel
(e)	/ʈ/	($_ω$[t], [Ct]	phonotactic restrictions on retroflexes
(f)	/ʈt/	[ʈʈ]	local assimilation of retroflexes
	/ʈVt/	[ʈVʈ]	non-local assimilation of retroflexes

The following subsections 6.3.1 – 6.3.6 will analyse the processes (15a) – (15f), in that order.

6.3.1 Retroflexion via rhotics

Section 4.1.2 proposed two possible explanations for the process of retroflexion in rhotic context in (15a), repeated here in (16). Processes with a reversed order of rhotic and retroflex are not discussed here, as they can be treated identically.

(16) (a) rt > ɽt > ɽʈ > ʈ staged process (diachronically only)
 (b) rt > ʈ

The process in (16a) involves several stages of the historical development, whereas (16b) consists of only one stage. Let us start with formalizing (16b). This process involves the collapse of two segmental categories with different manners but similar place into one (with different place), which can be expressed via the articulatory markedness constraint *DISTANCE (manner) defined above in (10c). Furthermore, the collapse involves a change in surface representation compared to the underlying perceptual representation. Part of the perceptual representations of the two input segments /r/ and /t/, the occurring output /ʈ/, and another possible output /ɽ/ is given in table 6.1.

Table 6.1 Partial perceptual representations of /r/, /t/, /ʈ/ and /ɽ/, with features specifying place of articulation and for manner.

	r	t	ʈ	ɽ
place	–2F3	0F3	–2F3	–2F3
manner	2trill	2stop	2stop	1trill 1stop

The trill /r/ in the first column and the flap /ɽ/ in the last column are both assigned the perceptual manner feature [trill], since a trill with a single contact sounds like a flap (Ladefoged & Maddieson 1996: 237). They differ in feature value, however: the trill has the value [2trill] and the flap the value [1trill], since the latter segment sounds less trill than the former. Both stop and flap are specified by the feature [stop], because flaps very often behave phonologically like stops. Again, the two segments differ in the feature values: stops are [2stop] and flaps [1stop].

The output in (16b) is unfaithful to the underlying form in two ways: it violates *DELETE (0F3) since the underlying sequence [-2F3, 0F3] is realized as [-2F3], and it violates *DELETE (trill), since the underlying sequence trill – stop is realized as stop. This is formalized in the tableau in (17) on the next page, which models the retroflexion rule in Norwegian.

The faith constraints *DELETE (–2F3) and *DELETE (stop) secure the features [–2F3] (of a rhotic or a retroflex) and [stop], respectively. The winning candidate does not violate any of these, as it contains both features in the output.

(17)

/rt/	*DELETE (–2F3)	*DELETE (stop)	*REPLACE (2stop, 1stop)	*DISTANCE (manner)	*DELETE (trill)
[rt]				*!	
☞ [ʈ]					*
[r]		*!			
[t]	*!				*
[ɽ]			*!		

The constraint *REPLACE (2stop, 1stop) is necessary to exclude the last candidate, the flap, which does not violate *DELETE (stop) since it contains stop cues. *REPLACE (2stop, 1stop) has to be ranked below *DELETE (stop) because it is worse to delete the whole [2stop] feature than to replace its value by [1stop]. *DELETE (stop) must be higher ranked than *DELETE (trill) in Norwegian, as the winning candidate is faithful only to the underlying stop specification, not to the trill specification.

In section 4.1 we saw an example of a language where the winning candidate is faithful to the trill specification: in Yidgha, the sequence /rt/ developed to the retroflex /ɽ/. This development can be accounted for by a reverse ranking of the *DELETE (trill) and *DELETE (stop) constraints than in (17) (the ranking of *REPLACE (2stop, 1stop) below *DELETE (stop) remains fixed, of course). A complication in the Yidgha development is the manner change from a trill to a flap. The flap emerges as the winning candidate because it secures both manner features of the underlying specification.

(18)

/rt/	*DELETE (–2F3)	*DELETE (trill)	*DISTANCE (manner)	*DELETE (stop)	*REPLACE (2stop, 1stop)
[rt]			*!		
[ʈ]		*!			
[r]				*!	
[t]	*!	*			
☞ [ɽ]					*

To account for the order of the input segments, i.e. for the fact that the rhotic has to occur to the left of the target segment, we have to assume either context-sensitive faith constraints or context-sensitive markedness constraints. These context-sensitive faith constraints and their rankings would look like (19a) for Norwegian and (19b) for Yidgha, and the context-sensitive markedness constraints and their rankings like (20a) for Norwegian and (20b) for Yidgha, where *A* stands for all apical alveolars, and *r* for a trill.

(19) (a) *DELETE (trill / A_) >> *DELETE (trill / _A)
(b) *DELETE (stop / _r) >> *DELETE (stop / r_)

(20) (a) *DISTANCE (trill, non-trill) >> *DISTANCE (non-trill, trill)
(b) *DISTANCE (trill, stop) >> *DISTANCE (stop, trill)

The second explanation for retroflexion in a rhotic context with subsequent drop of the rhotic, (16a), has to be modelled in three diachronic stages, given in (21).

(21) (a) r > ɽ
(b) ɽt > ɽʈ
(c) ɽʈ > ʈ

Consider the process at stage one, shown in (21a), which describes the change of an apical rhotic into a retroflex one, caused by articulatory variation. As we already saw in the development in Yidgha, the apical trill and the retroflex flap show little perceptual difference. The trill, however, requires a more precise articulation than a flap, which is expressed by a *PRECISION (trill) constraint being higher ranked than a *PRECISION (flap) constraint, see (14) above. The only constraint preventing a development as in (21a) is the faith constraint *REPLACE (2trill, 1trill), which tries to make sure that the trill feature is realized as a trill and not as a flap. If both constraints are unranked with respect to each other, variation will emerge, as in (22):

(22)

/r/	*DELETE (trill)	*PRECISION (trill)	*REPLACE (2trill, 1trill)
☞ [r]		*	
☞ [ɽ]			*
[t]	*!		

This tableau is interpreted as the front apical rhotic winning in approximately 50 percent of the cases, and the retroflex rhotic in the other 50 percent of the cases (see Anttila 1995, Bermúdez-Otero 1996, and Löhken 1997 for OT models with such free variation). Let us assume that this variation eventually ceases and that the retroflex flap emerges as the established pronunciation of the rhotic in such a language (this might be caused by *PRECISION (trill) eventually being higher ranked than *REPLACE (2trill, 1trill)).

The next stage in the development of a retroflex series is the assimilation of a following alveolar to the retroflex rhotic, see (21b). Here, only a change in the place of articulation takes place, which is perceivable as a change from a sequence [–2F3, 0F3] to a continuous [–2F3]. This development is illustrated in tableau (23).

(23)

/ɽt/	*DELETE (–2F3)	*DELETE (trill)	*DELETE (2stop)	*DISTANCE (tip)	*DELETE (0F3)
[ɽt]				*!	
☞ [ɽʈ]					*
[ɽ]			*!		*
[t]	*!	*			
[ʈ]		*!			*
[rt]	*!				

In tableau (23) the constraint *DISTANCE (tip) militates against the change from one apical place of articulation to another, recall (10a). The faith constraints securing the trill and stop manner cues, as well as those for retroflex place, are ranked higher than the one for the alveolar place (*DELETE (0F3)), thus candidates three, four, and five, which delete either one manner or the retroflex, are worse than candidates one and two, which preserve both manner and retroflexion. The first candidate, which is most faithful to the input, loses due to the effort saving constraint *DISTANCE (tip) being ranked higher than the faithfulness constraint for the alveolar.

The third and last stage of the development of a retroflex series, (21c), is the reduction of the sequence rhotic retroflex plus retroflex of another manner to the non-rhotic retroflex. This process obviously involves ranking the faith constraint for the rhotic feature lower than in previous stages, and ranking the constraint *DISTANCE (manner) higher.

(24)

|ɽʈ|	*DELETE (2stop)	*DISTANCE (manner)	*DELETE (1trill)
[ɽʈ]		*!	
☞ [ʈ]			*
[ɽ]	*!		

6.3.2 Retroflexion via back vowels

As illustrated in section 4.2, front apicals can retroflex in a back vowel context. In Margany, for instance, the underlying sequence /un/ is produced as [uɳ]. The perceptual representations of these segments plus that of /i/ are given in table 6.2 (based on the specifications in table 5.11 and 5.12).

Table 6.2 Perceptual representations of /n/, /ɳ/, /u/ and /i/.

	n	ɳ	u	i
[F1]			–3	–3
[F2]	+1	+1	–4	+4
[F3]	0	–2	–2	
manner-specific	nasal	nasal		

The affinity of back vowels and retroflexes was described in 4.2 as articulatorily as well as perceptually motivated. Perceptually, a re-association of the [–2F3] of [u] as belonging to the formant structure of the consonant can occur. Articulatorily, a reduction of gestures occurs: the input sequence involves a tongue back gesture from the retracted /u/ to the non-retracted front coronal. In the output sequence, both [u] and retroflex are retracted. The reduced number of gestures can be captured by the *DISTANCE (back) constraint as defined in (10b), which militates against a change in tongue back position. The gestural change violates *DELETE (0F3) since the underlying sequence [–2F3, 0F3] is realized as a continuous [–2F3].

(25)

/un/	*REPLACE (–4F2, +4F2)	*DISTANCE (back)	*DELETE (0F3)
[un]		*!	
☞[uɳ]			*
[in]	*!		

The ranking of the perceptual faith constraint *REPLACE (–4F2, +4F2) above the faith constraint *DELETE (0F3) prevents a change from [u] to [i] in the output; instead, the consonant assimilates to the retracted tongue back of the vowel.

In section 4.2.2 it was observed that primarily nasals, laterals, and rhotics undergo such a change towards a retroflex place of articulation. Stops mainly change only if the other manner classes changed, too. This asymmetrical behaviour is due to the fact that nasals, laterals, and rhotics have weak place cues, which can hardly be distinguished from each other. In our OT analysis such a difference in manner can be expressed by faith constraints for stops being higher ranked than those for nasals, laterals, and rhotics.[3] The fact that in Margany apical nasals are retroflexed in back vowel context, but stops are not, (see section 4.2.1), can now be formalized with the two manner-specific faith constraints in (26).

(26) *DELETE (0F3 / plosives) >> * DELETE (0F3 / nasals)

Tableaux with this ranking and the two underlying forms /un/ and /ut/ are given in (27a) and (27b). In this tableau it becomes obvious that the two constraints *REPLACE (–4F2, +4F2) and *DISTANCE (back) have to be ranked with respect to each other in Margany (*REPLACE (–4F2; +4F2) has to be ranked above *DISTANCE (back)), otherwise [it] and [ut] would both be possible outputs of /ut/, which is not the case.

(27)

/un/	*DELETE (0F3 / stops)	*REPLACE (–4F2, +4F2)	*DISTANCE (back)	*DELETE (0F3 / nasals)
[un]			*!	
☞[uɳ]				*
[in]		*!		

/ut/	*DELETE (0F3 / stops)	*REPLACE (–4F2, +4F2)	*DISTANCE (back)	*DELETE (0F3 / nasals)
☞ [ut]			*	
[uʈ]	*!			
[it]		*!		

[3] See Boersma (1998: 217ff.) for an elaboration of the asymmetry in place assimilations and their formalization as implicational universals.

6.3.3 Non-occurrence of retroflexes with front vowels or palatalization

Section 4.3 gave examples of retroflex segments avoiding a front vowel context. This avoidance is realized in two ways, either by a change of the retroflex into an alveolar, or by a change of the front vowel. These avoidance processes are summarized in (28) and (29). Again, only one order of vowel and retroflex sequence is illustrated here, the reverse order follows from the same analysis (with context-sensitive constraints accounting for the direction of the process, as illustrated for retroflexion in rhotic context in (19) and (20)).

		input	*output*	*process*
(28)		/iʈ/	[it]	de-retroflexion
(29)	(a)	/iʈ/	[ɨʈ] or [ɯʈ]	retraction
	(b)	/ɛʈ/	[æʈ]	lowering
	(c)	/iʈ/	[iəʈ]	diphthongization (schwa insertion)
	(d)	/iʈ/	[yʈ]	rounding

Both strategies were also observed for secondary palatalization of retroflexes, see (27a) and (27b). Furthermore, secondary palatalization can also be realized as a separate palatal glide, see (27c).

		input	*output*	*process*
(30)	(a)	/ʈ^{j}/	[t^{j}]	de-retroflexion
	(b)	/ʈ^{j}/	[ʈ]	de-palatalization
	(c)	/ʈ^{j}/	[ʈj]	separate palatal

Let us look at front vowel – retroflex sequences first. As in the case of retroflexion in a back vowel context, accounted for in the previous section, the cause of avoidance of the front vowel context is that retroflexes have a flat tongue middle and a retracted tongue back. Front vowels, on the other hand, have a raised and fronted tongue middle. The change in tongue position from front vowels to retroflexes or vice versa requires a large gestural movement within a short time. This articulatory difficulty can be expressed by the markedness constraint *DISTANCE (back). Furthermore, the non-synchronicity of the gesture of tongue middle lowering (at the end of the vowel) with the gesture of tongue tip raising and closure (at the beginning of the retroflex) is accounted for with the *SYNC (vowel | retroflex) constraint as defined in (12). With these constraints in hand, we can now formalize the different avoidance strategies illustrated in (28) and (29).

6.3.3.1 De-retroflexion

Processes like (28), in which a segment is de-retroflexed before or after a front vowel, can be accounted for in a similar way as the retroflexion in back vowel context depicted in (25): the faith constraint securing the unchanged vowel and the *DISTANCE (back) constraint that militates against a tongue back movement are ranked above the faith constraint for the retroflex, see tableau (31) on the next page.

(31)

/iʈ/	*REPLACE (+4F2, –4F2)	*DISTANCE (back)	*DELETE (–2F3)
[iʈ]		*!	
[uʈ]	*!		
☞ [it]			*

The most faithful, first output candidate violates the constraint against a change in the tongue back position from retracted to fronted. The second candidate, with a back vowel instead of the underlying front vowel, violates the very high ranked *REPLACE (+4F2, –4F2) constraint that secures the vowel cues.

6.3.3.2 Vowel retraction and lowering

Let us now look at the cases with a change in the vowel quality, see (29). These processes occur in languages in which some gestural markedness constraints such as *DISTANCE (back) and *SYNC (vowel | retroflex) are higher ranked than the faith constraints for the vowels. Vowel retraction and vowel lowering can be modelled by high-ranked *DISTANCE (back) constraints, which have to be further refined for this purpose. Vowel retraction is caused by the large gestural distance between /i/ and the retroflex, stated as *DISTANCE (i-R) in (32).

(32) *DISTANCE (i-R): "The tongue does not move from raised middle and fronted back position for the high front vowel [i] to lowered middle and retracted back position for a retroflex, or vice versa."

The articulation of a distance from front high vowel to retroflex can be avoided by retracting the vowel to [ɨ] (as in Ponapean, Bunuba, Russian, or Polish). But even with this retracted tongue position, there is a distance to the retroflex gesture, because [ɨ] still involves a raising of the tongue middle (though no fronting of the tongue back). Articulating this distance between [ɨ] and a retroflex militates against the constraint *DISTANCE (ɨ-R). Some languages (such as Toda) have a further retraction of the high front vowel to [ɯ], where the tongue gesture is very close to that of the retroflex consonant. This distance is captured by the constraint *DISTANCE (ɯ-R). The decreasing gestural distances of the three vowel – retroflex combinations can be represented by ranking the three *DISTANCE (vowel – retroflex) constraints in the following way.

(33) *DISTANCE (i-R) >> *DISTANCE (ɨ-R) >> *DISTANCE (ɯ-R)

The ranking in (33) can be regarded to be universal in the sense that it is phonetically inviolable: the distance between the articulatory position for an [i] and that of a retroflex is always larger than that between the gesture of an [ɨ] and a retroflex. The universal ranking in (33) is part of the phonetic space where language-specific phonetic cues and gestures are chosen from, and is therefore specified in the phonetics of a speaker. It is, however, not present in every language-specific phonology, only in those that employ all gestures specified in this hierarchy: a language without any retroflex category does not contain the hierarchy in (30) in its phonology. Furthermore, the hierarchy interacts with language-specific faithfulness constraints in languages that employ retroflexes and all three vowel categories. This point will be further illustrated below.

Vowel retraction occurs also for the mid front vowel /e/, which retracts to the less distant [ɘ] before a retroflex for example in Ponapean. This is given by the universal constraint hierarchy in (34).

(34) *DISTANCE (e-R) >> *DISTANCE (ɘ-R)

As far as vowel *lowering* is concerned, the retraction hierarchies in (33) and (34) are inappropriate. We have to assume the same maximal distance for the high front vowel and the retroflex, i.e. the same *DISTANCE (i-R) constraint is ranked highest. The constraint on the other end of the hierarchy, however, militates against the distance between the retroflex and the lowest vowel [a], i.e. *DISTANCE (a-R), which is the minimal distance one can get for the process of high front vowel lowering. In-between these two extremes, constraints against articulating the distance between retroflex and [e], [ɛ], and [æ], respectively, can be stated. This results in the universal ranking given in (35).

(35) *DISTANCE (i-R) >> *DISTANCE (e-R) >> *DISTANCE (ɛ-R) >>
*DISTANCE (æ-R) >> *DISTANCE (a-R)

As we saw in section 4.3.2, vowel lowering is not restricted to the high front vowel, but sometimes also occurs with the high back vowel /u/ (e.g. in Kayardild, Gunya, Tamil, and Kannada). This vowel is lowered towards the mid back vowel [o] only; no further lowering (e.g. to the low back [ɑ]) occurs. The mid back vowel [o] has a lowered tongue middle and a slightly raised tongue back (towards the velum), and is thus nearly identical to the tongue position for a retroflex consonant. The nearly identical gestures of [o] and a retroflex result in a minimal distance for *DISTANCE (o-R), i.e., this constraint can be assumed to be lower ranked than any of the other distance constraints. For back vowel lowering, we can thus assume the following ranking:

(36) *DISTANCE (u-R) >> *DISTANCE (o-R)

The articulatory distance between [u] and a retroflex is the same as the distance between [ɯ] and a retroflex, since [u] and [ɯ] differ in the shape of the lips only. Thus, these two constraints are ranked equally. This and the fact that *DISTANCE (o-R) is the lowest ranked of all the *DISTANCE (back) constraints lead to a universal ranking of (33), (34), (35), and (36) as in figure 6.2 on the next page.

Violation of a higher-ranked *DISTANCE constraint implies simultaneous violations of the lower-ranked ones. The constraint rankings in figure 6.2 interact language-specifically with vowel faith constraints. A language with very high ranked vowel faith constraints (i.e. above *DISTANCE (i-R)) would disallow any vowel changes. Examples of other language-specific rankings are given below.

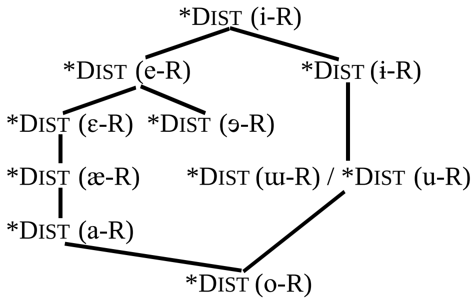


Figure 6.2 Ranking of *DISTANCE (back) constraints for vowel lowering and retraction, where the uppermost constraint *DISTANCE (i-R) is ranked highest, and the constraint *DISTANCE (o-R) is ranked lowest. The ranking of the constraints on the right side (responsible for vowel retraction) are not fixed with respect to those on the left side (responsible for vowel lowering). They can be ranked higher or lower (further developed in figure 6.3 and 6.4), as long as they preserve their inherent ranking.

Let us look at vowel retraction and vowel lowering successively.

Retraction. Taking the vowel retraction from /i/ to [ɨ] after retroflex fricatives in Russian as example, this process can be modelled as in (37), with a high-ranked *REPLACE (+4F2, –2F2) constraint militating against a retraction from /i/ to [ɯ], and a lower ranked *REPLACE (+4F2, +1F2), preventing a retraction from /i/ to [ɨ]. Between these two is ranked the *REPLACE (–2F3, 0F3) which prohibits a change in the retroflex fricative.

(37)

/ʂi/	*DIST (i-R)	*REPLACE (+4F2, –2F2)	*REPLACE (–2F3, 0F3)	*REPLACE (+4F2, +1F2)	*DIST (ɨ-R)
[ʂi]	*!				*
☞ [ʂɨ]				*	*
[si]			*!		
[ʂɯ]		*!		*	

In Toda, the front high vowel is retracted as far as the back vowel [ɯ], as given in tableau (38). The *REPLACE (+4F2, –2F2) constraint is lower ranked than in tableau (37), allowing a further retraction of the vowel to [ɯ].

(38)

/iʈ/	*DIST (i-R)	*REPLACE (–2F3, 0F3)	*DIST (ɨ-R)	*REPLACE (+4F2, –2F2)	*REPLACE (+4F2, +1F2)	*DIST (ɯ-R)
[iʈ]	*!		*			*
[ɨʈ]			*!		*	*
[it]		*!				
☞[ɯʈ]				*	*	*

Retraction of the high front rounded /y/ to the back [u], observable in Pingding Chinese, can be modelled in the same way as the vowel retraction in Toda (by replacing *DISTANCE (i-R) with *DISTANCE (y-R)), as rounding does not change anything in the distance between vowel and retroflexion gesture. This process is not illustrated here.

Ponapean shows retraction of the mid-front vowel /e/ to [ɘ], which is accounted for in (39), where *REPLACE (1trill, 2trill) militates against a change from underlying flap to surface trill.

(39)

/ɽe/	*DISTANCE (e-R)	*REPLACE (1trill, 2trill)	*REPLACE (+4F2, +1F2)
[ɽe]	*!		
☞[ɽɘ]			*
[re]		*!	

According to the general constraint hierarchy of *DISTANCE constraints in figure 6.2, this retraction implies that the high front vowel also retracts, if it exists in the language under consideration, since *DISTANCE (i-R) is ranked higher than *DISTANCE (e-R). And indeed, the Ponapean /i/ retracts to [ɨ], see the data in (21) in chapter 4. However, due to the flexible ranking of the constraints *REPLACE (vowel features), languages that only show a retraction of the mid vowel are possible.

The possible rankings of the markedness constraints for vowel retraction and the respective faith constraints for the vowels are summarized in figure 6.3.

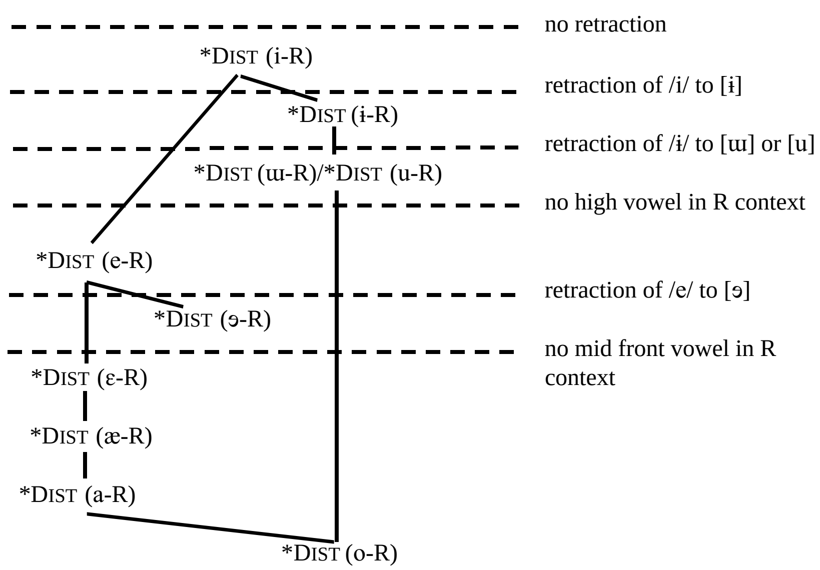


Figure 6.3 Ranking of the *DISTANCE (back) constraints and vowel place faith constraints (indicated by the dashed lines) for vowel retraction.

In figure 6.3, I make two assumptions. First, the constraints securing the F1 of the vowels (against vowel lowering) are ranked high (thus, lowering is not included in this figure). Second, all constraints on the F2 of the vowels are ranked at the same height, namely that of the dashed lines.

The position of the partial ranking *DISTANCE (e-R) >> *DISTANCE (ɘ-R) is not fixed in figure 6.3, i.e. it can be placed higher than indicated here, as is the case for Ponapean, see figure 6.4 below. This partial ranking, however, has to stay lower than *DISTANCE (i-R), since the gestural distance between [i] and a retroflex is unquestionably larger than that between [e] and a retroflex.

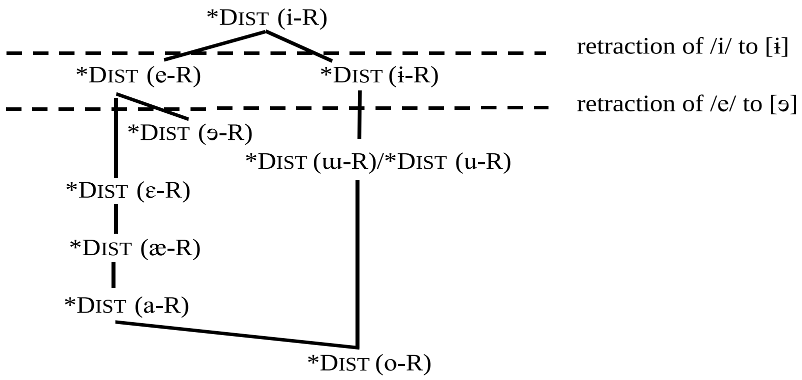


Figure 6.4 Ranking of the *DISTANCE (back) constraints and vowel height faith constraints (indicated by the dashed lines) for vowel lowering in Ponapean.

In figure 6.4, two rankings for the vowel faith constraints are possible: either *REPLACE (+4F2, –2F2), which militates against the change from [i] to [ɯ], is ranked below *DISTANCE (i-R), i.e., at the height of the first dashed line, or below *DISTANCE (ɨ-R) and *DISTANCE (e-R), i.e., at the height of the second dashed line. The vowel faith constraint *REPLACE (+4F2, +1F2), against a change from [e] to [ɘ] has to be ranked below the second dashed line. If it were ranked higher, no retraction of [e] would take place.

Lowering. Vowel lowering and the different rankings necessary to account for it are depicted in figure 6.5 on the next page. Here, the F2 faith constraints are assumed to be ranked high (no vowel retraction occurs) and all the vowel faith constraints are at the same height (at that of the dashed lines).

For the process of vowel lowering, Kayardild will be discussed as a representative language. In this language both high front /i/ and high back /u/ are lowered. The respective rankings are shown in figure 6.6, also on the next page.

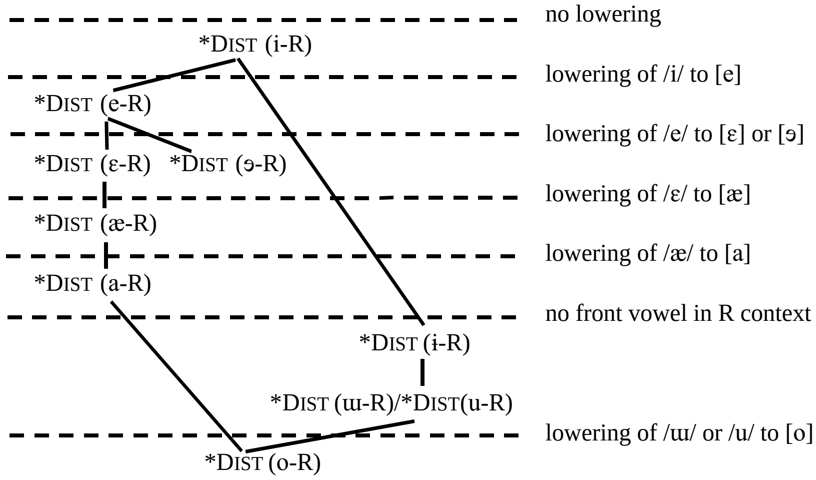


Figure 6.5 Ranking of the *DISTANCE (back) constraints and vowel height faith constraints (indicated by the dashed lines) for vowel lowering.

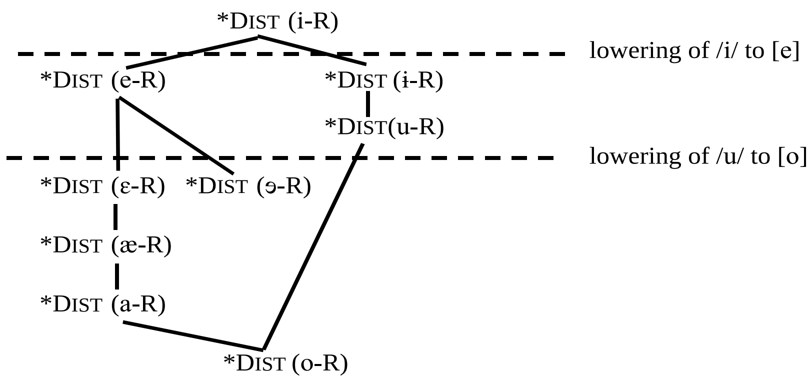


Figure 6.6 Ranking of the *DISTANCE (back) constraints and vowel height faith constraints (indicated by the dashed lines) for vowel lowering in Kayardild.

The two lowering processes in Kayardild are given in (40) (in the following tableaux the candidate with a faithful vowel but a changed retroflex and the respective constraint are not included anymore). The vowel faith constraint *REPLACE (–3F1, –1F1), which militates against a change from /i/ to [e] and from /u/ to [o], has to be lower ranked than the *DISTANCE (e-R) and *DISTANCE (u-R) constraints, otherwise no vowel lowering would take place. The vowel faith constraint *REPLACE (–3F1, +1F1) has to be high ranked to avoid a further lowering of /i/ to [ɛ], see the third candidate [ɛʈ].

(40)

/iʈ/	*DIST (i-R)	*REPLACE (–3F1, +1F1)	*DIST (e-R)	*DIST (u-R)	*REPLACE (–3F1, –1F1)	*DIST (o-R)
[iʈ]	*!		*			
☞ [eʈ]			*		*	
[ɛʈ]		*!			*	

/uʈ/	*DIST (i-R)	*REPLACE (–3F1, +1F1)	*DIST (e-R)	*DIST (u-R)	*REPLACE (–3F1, –1F1)	*DIST (o-R)
[uʈ]				*!		*
☞ [oʈ]					*	*

The vowel lowering process in Norwegian is phonetically unusual, as it involves lowering of the mid front vowel /ɛ/ only (recall the data from (25) in chapter 4), see (41).

(41)

/ɛʈ/	*REPLACE (+1F1, +3F1)	*DISTANCE (ɛ-R)	*REPLACE (+1F1, +2F1)	*DISTANCE (æ-R)
[ɛʈ]		*!		
☞ [æʈ]			*	*
[aʈ]	*!		*	

The high front vowel /i/ in Norwegian does not change, although we would expect it from our universal phonetic constraint ranking in figure 6.2 and 6.4 to undergo lowering, since the *DISTANCE (i-R) constraint is higher ranked than the *DISTANCE (ɛ-R) constraint. This exception has to be treated as language-specific and phonetically unmotivated, formalized by a high faith constraint for the vowel /i/, see (42).

(42)

/iʈ/	*REPLACE (–3F1, –1F1)	*DISTANCE (i-R)	*DISTANCE (e-R)
☞ [iʈ]		*	*
[eʈ]	*!		*

Therefore Norwegian is assumed to show the following interaction of *DISTANCE constraints and perceptual faith constraints (*REPLACE) with respect to the process of vowel lowering, where the constraint *REPLACE (–3F1, –1F1) militates against the lowering of /i/ (very high ranked), and the constraint *REPLACE (+1F1, +2F1) against the lowering of /ɛ/.

(43) *REPLACE (–3F1, –1F1) >> *DISTANCE (i-R) >> *DISTANCE (ɛ-R) >> *REPLACE (+1F1, +2F1) >> *DISTANCE (æ-R)

6.3.3.3 Vowel diphthongization

Vowel diphthongization differs from the processes of vowel lowering and retraction, in that it involves a change of part of the vowel only. During the articulation of the vowel the tongue retracts, lowers, or assumes a neutral position, before moving on to the retroflex articulation. This near-neutral position results in a schwa-like offglide, and thus a diphthongization of the vowel. The present analysis is not concerned with the exact phonetic realization of the second half of the vowel. It is represented as a schwa, but if a retracted front high vowel or a front mid vowel were assumed, the formalization would not change. The articulation responsible for such a vowel change can be modelled with the *SYNC (vowel | retroflex) constraint defined in (12): the tongue middle lowering is not synchronized with the tongue tip raising and closure, and thus occurs already when the tongue tip is not raised yet. The reverse process, a raising of the tongue tip far before a tongue tip closure is made, occurs in the process of vowel retroflexion, discussed in section 6.3.4 below. Vowel retroflexion is also accounted for by *SYNC (vowel | retroflex).

Diphthongization of /i/ in Gugada is taken here as an example to show the relevant constraint interaction, see tableau (44).

(44)

/iʈ/	*REPLACE (+4F2, +1F2)	*SYNC (vowel | retroflex)	*INSERT (0F1 & 0F2)
[iʈ]		*!	
[ɨʈ]	*!	*	
☞ [iəʈ]			*

The winning candidate does not violate any vowel faith constraint, for instance *REPLACE (+4F2, +1F2) if vowel retraction is assumed, because the vowel is, at least partly, still perceivable. [iəʈ] does, however, violate a *INSERT (0F1 & 0F2) constraint since a new segment feature (the schwa) emerges that was not specified in the underlying representation.

6.3.3.4 Vowel rounding

The vowel rounding processes in Wembawemba and Wergaia are assumed here to occur only together with de-retroflexion, following Flemming's (1995, 2002) proposal discussed in sections 4.3.3 and 5.3.1. Vowel rounding can thus be interpreted as a strategy to preserve the underlying retroflex specification, i.e. [–2F3], as rounding causes a similar cue of lowered F3, by realizing it on the vowel. An example illustrating vowel rounding is modelled in tableau (45).[4]

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[4] The possible candidate [it^w] that was introduced in the discussion on vowel rounding by Flemming in section 5.3.2 is not included in this tableau. In order not to let this candidate win, information on the low perceptibility of the feature [–2F3] on a stop, compared to its high perceptibility if it is realized on a vowel, has to be included. This can be done by incorporating the probability of the features to be properly perceived, i.e. categorized, see Boersma (1998: 285f.).

(45)

/iɽ/	*DISTANCE (i-R)	*DELETE (–2F3)	*REPLACE (+4F2, +2F2)	*DELETEPATH (stop × –2F3)	*GESTURE (lips)
[iɽ]	*!				
[it]		*!		*	
☞[yt]			*	*	*

The most faithful candidate is articulatorily too complex and violates the high-ranked *DISTANCE (i-R) constraint. The second candidate is articulatory less complex, but does not realize the underlying [–2F3] specification. The winning candidate preserves this feature but violates the faith constraints *REPLACE (+4F2, +2F2) and *DELETEPATH (stop × –2F3), the latter militating against the movement of the [–2F3] feature from the consonant to the vowel (recall the definition of *DELETEPATH in (5)). Furthermore, the winner violates the markedness constraint *GESTURE (lips), because it includes additional rounding of the lips. In Wembawemba and Wergaia, these three constraints have to be lower-ranked than the constraint preserving the [–2F3] feature value and the constraint against a gestural movement from front high vowel to retroflex. This ranking is unexpected since there is no observable optimisation, neither articulatory nor perceptual. Perceptually, the faithfulness to both underlying segment classes (low ranked *REPLACE (+4F2, +2F2) and *DELETEPATH (stop × –2F3)) is less important than the preservation of one single cue (high ranked *DELETE (–2F3)). Articulatorily, one gesture is saved (expressed by the high ranked *DISTANCE (i-R)) at the cost of having an additional gesture (the low ranked *GESTURE (lips)). This unusual ranking might explain why such a process is cross-linguistically extremely rare.

In sections 4.3.2.1 and 4.3.3, Koḍagu was shown to retract vowels before retroflexes, and retract and round vowels between a labial and a retroflex. The example word [poːɽ] is analysed in (46), assuming /peːɽ/ as the non-rounded and non-retracted input to the diachronic development in Koḍagu. A *SYNC constraint that militates against the synchronization of the end of labialization and the beginning of the vowel, termed *SYNC (labial | vowel), can account for the rounding of the following vowel.

(46)

/peːɽ/	*DISTANCE (e-R)	*SYNC (labial | vowel)	*REPLACE (+4F2, –4F2)	*REPLACE (+4F2, –2F2)
[peːɽ]	*!	*		
☞ [poːɽ]			*	*
[pøːɽ]	*!			
[pɤːɽ]		*!		*

Both the first, most faithful candidate and the third candidate, which shows no retraction but only vowel rounding, violate the *DISTANCE (e-R), because they do not reduce the distance between the vowel and the retroflex gesture. The fourth candidate, without rounding, reduces the gestural distance, but violates the *SYNC (labial | vowel) constraint, which is higher ranked than the vowel faith constraints. Thus, the rounded, retracted vowel wins.

6.3.3.5 Secondary palatalization

For secondary palatalization of retroflexes, the account looks slightly different from those for the vowel – retroflex sequences with respect to possible outputs. Since the articulation of a palatalized retroflex is assumed here to be impossible (as illustrated in section 2.5), there is no possible output candidate of this type. Instead, the three realizations as given in (30) and repeated here in (47) are observable in natural languages. Let us discuss them subsequently.

		input	*output*	*process*
(47)	(a)	/ʈʲ/	[tʲ]	de-retroflexion
	(b)	/ʈʲ/	[ʈ]	de-palatalization
	(c)	/ʈʲ/	[ʈj]	separate palatal

The first realization of retroflex palatalization is a non-retroflex, palatalized segment. This process can be found in Russian for the fricative /ʂ/, which palatalizes to the segment [ʃ] (the palato-alveolar fricative shows some inherent palatalization due to its domed tongue body, and is thus not represented with additional secondary palatalization). Palatalization of coronals is realized as a raising of the second and third formant, and will be represented here by the feature [+2F3]. The constraint *DELETE (+2F3) thus militates against the deletion of the palatalization cues.

(48)

/ʂ+ʲ/	*DELETE (+2F3)	*REPLACE (–2F3, +2F3)
[ʂ]	*!	
☞ [ʃ]		*

Since the non-realization of palatalization cues is not an option in the symmetric system of Russian consonants, which are either palatalized or non-palatalized, the constraint *DELETE (+2F3) is very highly ranked and prohibits the non-palatalized first candidate. Instead, a change in the inherent cues of the fricative from retroflex to palato-alveolar is acceptable. Thus, the second candidate wins.

The reverse ranking of the two faith constraints results in the realization of the retroflex as non-palatalized, the second output occurring for the process of palatalizing retroflexes, as depicted in (47b). This strategy can be found in Lewis Scots Gaelic, illustrated in section 4.3.2.5. The following tableau accounts for the underlying sequence /ʈ+ʲ/ in the Lewis dialect:

(49)

/ʈ+ʲ/	*REPLACE (–2F3, +2F3)	*DELETE (+2F3)
☞ [ʈ]		*
[tʲ]	*!	

A problem concerning this realization strategy is the fact that the resulting form is ambiguous, since the hearer is not provided with any perceptual cues as to whether the segment is palatalized or not. The Lewis form [paːʈ] 'a poet', for example, can be both nominative singular (without underlying palatalization) and genitive singular (with underlying but not realized palatalization for the genitive). Additional contextual information is needed to disambiguate the two forms.

The last possibility of realizing palatalization on a retroflex segment is doing so not simultaneously but instead with a following palatal glide (45c). It was claimed in 2.5.2 that this is the strategy applied in Toda. Toda palatalization of retroflexes can therefore be modelled as follows, where *DELETEPATH (stop × +2F3) militates against a change in the overlap of palatalization and stop cues (see definition of *DELETEPATH constraints in (5)).

(50)

/ʈ+ʲ/	*REPLACE (–2F3, +2F3)	*DELETE (+2F3)	*DELETEPATH (stop × +2F3)
[ʈ]		*!	
☞ [ʈj]			*
[ʈʲ]	*!		

As explained in section 2.5.2, Toda is assumed to have a phonological category of a palatalized retroflex, though articulatory this is impossible. Some special restriction must be therefore assumed in the perception grammar to prevent the listener from categorizing the articulatory output [ʈj]$_{art}$ as two consecutive segments, analysing it as one complex segment [ʈʲ] instead. In a perception grammar, so-called *WARP constraints (Boersma 1998: 164) require that the cues of a segment given in the input are categorized as such. For our purpose, a *WARP (+2F3) constraint requires that the input segment [j]$_{art}$ is categorized as such, and the *WARP (stop | +2F3) constraint that the input [ʈj]$_{art}$ is perceived as the sequence of the two segments [ʈj]$_{perc}$.[5] This perception process is modelled in tableau (51).

(51)

[ʈj]$_{art}$	*/ʈj/	*WARP (+2F3)	*WARP (stop | +2F3)
[ʈj]$_{perc}$	*!		
☞ [ʈʲ]$_{perc}$			*
[ʈ]$_{perc}$		*!	

The constraint */ʈj/ is a language-specific phonotactic constraint acquired by the learner via probabilistic knowledge of the occurrence of specific segment sequences in the language. It prohibits the categorization of the sequence [ʈj]$_{art}$ as [ʈj]$_{perc}$ because the glide /j/ does not occur in this position in Toda, and it thus prevents the most faithful first candidate from winning. The third candidate, the one without the glide, violates the high ranked *WARP (+2F3) constraint. The [ʈj]$_{art}$ sequence,

5 Boersma's *WARP constraints are applied only to single vowel segments and used to model the miscategorization of these vowels as acoustically very close ones. This constraint family is not applied by Boersma to segmental sequences as done here.

therefore, can only be interpreted as a palatalized retroflex.

It must be noted that there is a slight mismatch exemplified in (50) and (51). The faith constraints in (50) refer to rich perceptual features, whereas the perceptual results of (51) are more abstract featural representations (in accordance with Boersma 1998).[6]

6.3.4 Retroflexion of vowels

Retroflexion of vowels was illustrated in section 4.5.2 to originate from a tongue tip raising at the beginning of the vowel gesture. This is a different kind of non-synchronization of vowel and retroflex gestures than described for the diphthongization in section 6.3.3.3. It is caused, however, by the same drive of avoiding effortful synchronizations of gestures, captured by the *SYNC (vowel | retroflex) constraint as defined in (12) above. Vowel retroflexion of /a/ in Margany, for example, can then be accounted for as follows:

(52)

/aʈ/	*SYNC (vowel | retroflex)	*INSERTPATH (–3F3 × +3F1)
[aʈ]	*!	
☞ [aˑʈ]		*

The non-synchronization of the two gestures results in a change in the vowel quality, which violates the *INSERTPATH (–3F3 × +3F1) constraint (see the definition of *INSERTPATH constraints in (4)).

6.3.5 Phonotactics of retroflex segments

Section 4.6 illustrated that retroflex segments often do not occur in those positions where the retroflex is not well perceivable, namely post-consonantally. This was accounted for by the weaker CV cues of retroflexes, which are perceptually close to those of apical alveolars, compared to the more distinct VC cues. Such a proposal was formalized already by Steriade (1995, 2001a), as discussed in section 5.3.3. Steriade assumes that these are cases of neutralization of apical contrast. In the following formalization I assume that phonotactic restrictions of this class are not explained by reference to its distinctiveness with the presence of other classes in the same inventory. Instead, it is assumed that the retroflex does not occur in specific positions in certain languages because its *GESTURE (retroflex) constraint interacts with a family of *DELETE (–2F3) constraints as defined in (2a) above, which are sensitive to the context restriction as given in (53).

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[6] If the grammar model exemplified in (51) is applied to (50) and all earlier tableaux in this chapter, the formulation of the faith constraints would have to be modified appreciably, since they would have to refer to abstract features. In (50) the perceptual part of the second candidate would become $[ʈ^j]_{perc}$, i.e., the winning candidate of (51). This means that the second candidate in (50) would become completely faithful to the underlying form, and hence would violate no faith constraints at all. A formulation of the current theory in terms of more abstract features has to be postponed until future research.

(53) *DELETE (–2F3 / V_V) >> *DELETE (–2F3 / V_C) >> *DELETE (–2F3 / C_V) >> *DELETE (–2F3 / C_C)

This ranking of contexts incorporates the fact that retroflex cues are most prominent in a V_V context, and least prominent in C_C context, like all consonantal cues. The ranking of the intermediate two constraints *DELETE (–2F3 / V_C) and *DELETE (–2F3/ C_V) incorporates that the VC cues of retroflexes are stronger than their CV cues. The constraint hierarchy in (53) is hence a universal comparison of the contrastiveness of retroflex cues in specific positions. As was the case for the universal gesture hierarchies for vowel retraction and vowel lowering in section 6.3.3.2, this hierarchy is phonetically motivated and assumed to be present in the universal phonetic knowledge. It does not exist in the phonology of every language. Languages with no retroflex gesture at all *could* be described as ranking *GESTURE (retroflex) above the complete hierarchy of (53). But as there is no need to refer to a non-learned gesture with a specific *GESTURE constraint and, more importantly, to include information on the possible contexts of occurrence for this non-existing segment class in the grammar of this language, such a formalization is not proposed here.

For a language such as Kashmiri which allows retroflex segments in all positions, the *GESTURE (retroflex) constraint could similarly be assumed to be ranked below the hierarchy in (53). But again, this language needs no further information on slight differences in the perceptibility of retroflex cues in specific positions, since these differences are not relevant for the phonology of this language. Therefore, the hierarchy in (53) is not assumed to be part of the grammatical knowledge of Kashmiri speakers. The hierarchy in (53) is only present in the grammar of a language if there are cue-specific prosodic restrictions. On the other hand, the Djapu dialect of Dhuwala-Dhuwal, a language with retroflex segments in postvocalic position only, has the *GESTURE (retroflex) constraint ranked between the *DELETE (–2F3 / V_C) and *DELETE (–2F3 / C_V) on the hierarchy, and this ranking is contained in the grammar.

Several languages, such as the Australian language Bunuba, have no retroflex in initial position. In section 4.6.2 it was proposed that this behaviour is not phonetically motivated, as it comprises both postvocalic and postconsonantal positions. This restriction has to be stored in the phonology language-specifically, namely as ranking of the *GESTURE (retroflex) constraint below faith constraints securing the retroflex features in non-initial context and above faith constraints for retroflex cues in general.

These languages do, however, allow a retroflex segment in word-initial position if the consonant in the following syllable is retroflex. These are cases of long-distance assimilation to be formalized in the next section, independent of the general phonotactics.

Lastly, some Australian languages show variation in the actual articulation of the retroflex (and the alveolar) in initial position, for instance observed by McGregor (1990) for Gooniyandi. For these cases, Boersma's *PRECISION constraints as defined in (13) can be applied to a specific context, see (54).

(54) *PRECISION (tongue tip: retroflexed | ($_{\omega}$_): “In word-initial position, the tongue tip does not work up the precision to put itself in a retroflex position.”

This lack of precision in the articulation of the retroflex segment may result in an apical alveolar (i.e. a non-displaced apical articulation) in some cases and therefore account for the variation found in languages such as Gooniyandi.

6.3.6 Assimilation of retroflexion

Assimilation processes are gesture reductions licensed by the weak perceptibility of the cues that are lost by the assimilation. In our FP-OT framework, apical assimilation involving retroflexes can be depicted as being triggered by a high-ranked *DISTANCE (tip) constraint (defined in (10a)), which militates against the change from one tongue tip posture to another. Furthermore, assimilation violates faith constraints of the segment changed. As was defined already above in section 6.3.5, the cues for retroflexes are stronger in VC position than in CV position, leading to a context-sensitive *DELETE (–2F3) constraint ranking for phonotactic restrictions in (55a), analogously to (53). A similar context hierarchy can be assumed for the constraint *DELETE (0F3) which militates against the deletion of the mid F3 cues of apical alveolars, see (55b).

(55) (a) *DELETE (–2F3 / V_) >> *DELETE (–2F3 / C_)
(b) *DELETE (0F3 / V_) >> *DELETE (0F3 / C_)

These two constraint rankings cannot be ordered with respect to each other in any specific way, as there is no motivation why for example the deletion of a retroflex before a vowel should be perceptually more acceptable than the deletion of an apical alveolar in the same environment. With these two constraint rankings and their flexible, language-specific ranking with respect to each other, the assimilation processes illustrated in section 4.7 can be modelled.

For *progressive* assimilation of an *alveolar to a retroflex* the two constraint families in (55) have interact as follows:

(56) *DELETE (–2F3 / V_) >> *DELETE (0F3 / C_)

The progressive and iterative assimilation in Swedish and Norwegian is illustrated in the tableau in (57), where just a consonant sequence but not the whole word is given. The sequence occurs after a vowel.

(57)

/ɳts/	*DISTANCE (tip)	*DELETE (–2F3 / V_)	*DELETE (0F3 / C_)
[ɳts]	*!		
☞ [ɳʈʂ]			**
[nts]		*!	

Progressive assimilation of a retroflex to an alveolar requires the ranking of the constraint saving the alveolar cues postvocalically above the constraint saving the retroflex cues postconsonantally, see (58).

(58) *DELETE (0F3 / V_) >> *DELETE (–2F3 / C_)

Kannada has such a process, illustrated in (59), which again only shows the relevant consonant clusters and the essential constraints.

(59)

/dɭ/	*DISTANCE (tip)	*DELETE (0F3 / V_)	*DELETE (–2F3 / C_)
[dɭ]	*!		
[ɖɭ]		*!	
☞ [dl]			*

For *regressive assimilation of an alveolar to a retroflex*, a ranking of all the faith constraints for the retroflex (55a) above the faith constraints for the alveolars (55b) must be assumed, see (60).

(60) *DELETE (–2F3 / V_) >> *DELETE (–2F3 / C_) >> *DELETE (0F3 / V_) >> *DELETE (0F3 / C_)

An example from Sanskrit is given in (61):

(61)

/tɖ/	*DISTANCE (tip)	*DELETE (–2F3 / C_)	*DELETE (0F3 / V_)
[tɖ]	*!		
☞ [ʈɖ]			*
[td]		*!	

The ranking in (60) predicts that *progressive* assimilation of alveolar to retroflex place of articulation occurs as well, i.e., that it is always the place cue of the retroflex that wins in Sanskrit. This proposal differs from Steriade's (1995) analysis of Sanskrit, which treats regressive assimilation of alveolars to retroflexes as being morphologically conditioned: spreading occurs from the cues of the content words to those of the functional words. Whitney (1889, §196) illustrates that retroflexes in Sanskrit can influence adjacent dentals, but does not describe the reverse process nor gives examples for it, thereby supporting the present analysis of Sanskrit.

Lastly, the process of *regressive assimilation of a retroflex to an alveolar* has to be discussed. This involves the following ranking of the cue constraints:

(62) *DELETE (0F3 / V_) >> *DELETE (0F3 / C_) >> *DELETE (–2F3 / V_) >> *DELETE (–2F3 / C_)

This process of regressive alveolar assimilation occurs in Punjabi, see (63).

(63)

/ɳn/	*DISTANCE (tip)	*DELETE (0F3 / C_)	*DELETE (–2F3 / V_)
[ɳn]	*!		
[ɳɳ]		*!	
☞ [nn]			*

Section 4.7.1 also included the *assimilation of a retroflex to a non-coronal* velar or palatal with the example of Colloquial Tamil. For such a process the *DISTANCE (back) constraint (as defined under 10b) that accounts for the unwillingness of a change in articulator from retracted tongue back for the retroflex to the raised tongue back for the velar has to be ranked above the coronal faith constraint *DELETE (+1F2), see (64) (the velar feature [–2F2] was introduced in table 5.10).

(64)

/ʈk/	*DISTANCE (back)	*DELETE (–2F2)	*DELETE (+1F2)
[ʈk]	*!		
[ʈʈ]		*!	
☞ [kk]			*

From the data at hand, we cannot determine whether the *DELETE constraints have to be formulated as context-sensitive or not, i.e. whether /ʈ/ is always assimilated independent of the context.

The examples of *long-distance assimilation* in section 4.7.2 were restricted to assimilation of an alveolar towards a retroflex, for the obvious reason that non-coronal segments are not affected by a distant retroflex. It was assumed that the retroflex gesture is held during the interval between the two surface retroflex segments. In contrast to local assimilation, it is not an adjacent gesture that is changed in this type of assimilation, and hence the direct context of the two segments involved in the process does not matter. It is a ranking between *REPLACE (0F3, –2F3) and *REPLACE (–2F3, 0F3) that simply decides on the winning cues and hence on the direction of assimilation.

The Sanskrit *nati rule* exemplifies *progressive long-distance assimilation.* Only the alveolar nasal can undergo it, and the output violates the manner-specific constraint *REPLACE (0F3, –2F3 / nasal), which militates against the replacement of an alveolar by a retroflex nasal. Tableau (65) illustrates the process. In the following examples, dots are used to indicate intervening, non-coronal material.

(65)

/ʂ...n/	*REPLACE (–2F3, 0F3)	*DISTANCE (tip)	*REPLACE (0F3, –2F3 / nasal)
[ʂ...n]		*!	
[s...n]	*!		
☞[ʂ...ɳ]			*

The *DISTANCE (tip) constraint is assumed to be sensitive to the change in place of articulation, only, but is not violated by a change from apical fricative to stop which also involves a slight change of tongue tip position.

Long-distance assimilation in Sanskrit is blocked by non-nasal coronals between the trigger retroflex and the nasal, see (66).

(66)

/ʂ̺.t.n/	*REPLACE (–2F3, 0F3)	*REPLACE (0F3, –2F3 / stop)	*DISTANCE (tip)	*REPLACE (0F3, –2F3 / nasal)
☞[ʂ̺.t.n]			*	
[s.t.n]	*!			
[ʂ̺.t.ɳ]			**!	*
[ʂ̺.ʈ̺.n]		*!	*	
[ʂ̺.ʈ̺.ɳ]		*!		*

The third candidate, in which /n/ is retroflexed after a retroflex despite the intervening alveolar, violates the *DISTANCE (tip) constraint twice because of the changes from retroflex to alveolar and from alveolar to retroflex articulation. The fourth candidate, a retroflexion of the plosive instead of the nasal, shows that it is necessary to distinguish the *REPLACE constraints according to the manner of the segments: stops with their stronger cues allow less changes than nasals, therefore *REPLACE (0F3, –2F3 / stop) is higher ranked than *REPLACE (0F3, –2F3 / nasal) (see Boersma's 1998 argumentation and Steriade's 2001 proposal). The last candidate, where both underlying apicals are retroflexed, violates both manner-specific *REPLACE constraints.

6.4 Conclusion

In the present chapter it was shown that processes involving retroflex segments could be modelled by assuming underlying perceptual representations, with additional articulatory restrictions on their realization. Underlying articulatory features are absent in my account. Furthermore the present chapter showed that is not necessary to stipulate additional devices such as a P-map (Steriade 2001a, b) that stores information on perceptual difference since the constraints in the grammar refer directly to cues and cue combinations. For the class of retroflexes, the low F3, i.e. the feature [–2F3], plays a large role in quite a number of processes. At the same time, the retraction of the tongue tip concomitant with retroflex articulation imposes restrictions on the realization of specific sequences and accounts for phonological processes such as front vowel lowering or retraction in a retroflex context or a change of the retroflex in secondary palatalization.

The analyses of the phonological processes were illustrated with mainly only one example language each from the respective sections in chapter 4. Examples from further languages given in chapter 4 were not discussed here in order not to obscure the analysis. Detailed accounts for these non-discussed languages, especially of languages that involve more than one process, are left for future work.

The analyses presented here included observations on cross-linguistic variations and descriptions of these variations with universal constraint hierarchies that interact with language-specific constraints. Two such cases were discussed, the process of vowel retraction and lowering (6.3.3.2), where universally ranked articulatory markedness constraints interact with perceptual faith constraints, and assimilation processes (6.3.6), where universally ranked faith constraints interacted with markedness constraints that are language-specifically ranked. As explained before, these rankings are grounded in the phonetic equipment of humans and are in this sense universal: either the constraint of a more complex articulation is higher ranked than one militating against a less complex articulation, or the constraint against a cue in a perceptually less salient context is higher ranked than the constraint against the same cue in a perceptually more salient context. These universal constraint hierarchies are assumed to be part of the phonetic knowledge available to a speaker, and not to belong to a separate innate Universal Grammar. Furthermore, they are not present in the phonology of every single language, but only in those that actually refer to these phonetic details in their phonological processes. The process of vowel lowering in Norwegian (see tableaux (41) and (42)) illustrated that a language can partly follow such universal hierarchies (the lowering of the vowel [ɛ]) but show idiosyncratic behaviour for other parts due to high-ranked faith constraints (as in the case of non-lowering of the vowel [i]).

In sum, the present chapter addressed and covered large parts of the discussion of all previous chapters of this dissertation: it dealt with the phonological processes involving retroflexes as illustrated in chapter 4 in the framework of FP introduced in chapter 5, thus summarized and brought to a conclusion the phonological part of this dissertation. Moreover, by specifying the class of retroflexes by perceptual features [–2F3] and [+1F2], based on the perceptual cues that were the topic of chapter 3, and by restricting their coarticulations by their articulatory characteristics, as described in chapter 2, it incorporated the phonetic definition of retroflexes given in the first part of the thesis.

7 Conclusion

The present dissertation has made two main proposals for the segmental class of retroflexes and for the interplay of phonetic cues and phonological features by looking in detail at the phonetic realizations and phonological behaviour of retroflexes.

Firstly, I defined the phonetic space from which languages choose their retroflex category by proposing four articulatory properties and two perceptual cues. The articulatory and perceptual properties, their restrictions, and possible improvements are discussed in section 7.1 below.

Secondly, I argued for a phonological representation of the class of retroflexes and the processes it undergoes that departs in two ways from traditional phonological approaches: it assumes an underlying perceptual representation, and it rejects the notion of universal phonological features. This point will be summarized in section 7.2, together with a model of the tongue parts that incorporates interdependencies between the single articulators.

The claims made above concerning the phonological representations imply that I assume there is no universal class of retroflexes. How this idea can be compatible with my search for general characteristics of retroflexion is the topic of section 7.3.

Section 7.4 gives an outlook on possible future research.

7.1 Phonetic characteristics of retroflexes

The class of retroflex segments is a heterogeneous class that shows large articulatory variation, as illustrated in chapter 2. Quite a number of the variants existing in natural languages do not show any bending backwards of the tongue tip, although this criterion is often used to define retroflexion. Simonsen et al. (2000), for example, argue that the apical post-alveolar segments in Norwegian are not retroflex because they are not articulated with a tongue tip bent backwards. Lee (1999) reasons similarly for the Mandarin post-alveolar fricatives. It was shown, however, that the segmental classes in these two languages share a number of articulatory characteristics with segments in other languages that are clearly retroflex, and that they, furthermore, show a similar phonological behaviour. This led to the assumption that a less restrictive definition for the articulatory class of retroflexes is needed. Further evidence for this need for a more flexible definition comes from phonetic variation within languages. It was shown that for a single language the retroflex class can vary between speakers and/or between contexts from an articulation with the underside of the tongue tip approaching or having contact with the post-alveolar or palatal region, i.e., the gesture that is referred to as tongue tip bending backwards, to an apical alveolar articulation.

Due to this large articulatory variation, I proposed an articulatory definition of retroflexion in chapter 2 using the following four criteria:

(1) (a) apicality
(b) posteriority
(c) sublingual cavity
(d) retraction

Posteriority, (1b), was shown in section 2.4 to be missing in some types of retroflex fricatives. Whereas the properties of apicality, posteriority, and sublingual cavity are fairly well established and have been mentioned before extensively in the phonetic literature (although in the case of apicality with a slightly more restricted definition), the proposal that retraction is present in *all* realizations of retroflexion is new, see the discussion in section 2.3. Since such a hypothesis can only be refuted on the basis of negative evidence, which I have not been able to find up to now, it is open for future research to show whether this property really holds for all languages or whether some language exists that has a non-retracted retroflex and thus provides counter-evidence.

The impossibility of proving that all retroflexes are retracted is a point of criticism to the present dissertation. The proposed four properties can be criticized on two more grounds. Firstly, the properties were generalized across all manners of articulation, although their application already showed that there are manner-specific differences: whereas retroflex stops are always posterior, retroflex fricatives very often lack this property. As a consequence, one could either assume different properties according to the manner of articulation, or that the proposed properties do not hold for all manners, i.e., stops have to be posterior, whereas fricatives do not. This idea could not be further developed here (for instance with respect to other manners such as nasals or rhotics) for lack of time and articulatory data.

The second point of criticism of the four properties is the apparent inconsistency in including implied properties. In section 2.3.4 I proposed that the property ‘retracted tongue back’ implies a flat, i.e., lowered, tongue middle, see (2a), and vice versa. The flat tongue middle can be proposed as a separate property, but I argue in the same section that this is redundant since a retracted tongue back cannot be achieved without a lowering (i.e., flattening) of the tongue middle. At the same time, I elaborate in section 2.3.5 that ‘posteriority’ implies a ‘sublingual cavity’, see (2b) (repeated from (8a) in chapter 2), but still propose that the implied characteristic of sublingual cavity is a separate property.

(2) (a) retraction $\rightarrow$ flatness
(b) posteriority $\rightarrow$ sublingual cavity

This inconsistency can be remedied either by postulating that flatness is a separate property of retroflexion, or by leaving out both flatness and sublingual cavity as separate properties since they are implied by others. I reject the latter possibility since this runs into problems if one assumes a manner-specific absence/presence of properties. As was indicated above, fricatives do not have to fulfil the property of posteriority. If sublingual cavity is taken only as an implicational property of posteriority, then this would mean that fricatives have to satisfy neither posteriority nor sublingual cavity; a result that is clearly not advantageous, given that even the implications might hold for specific manners only.

In section 2.3.2 the gesture of flapping out was described as a "possible concomitant of" posteriority and apicality, which could be interpreted as a further implication, see (3).

(3) posteriority & apicality $\rightarrow$ flapping out

This implication is, however, a simplification since flapping out depends very much on the manner of articulation: a quick movement of the tongue tip as required for stop releases and for flaps enables a flapping out, whereas more static positions of the tongue tip as necessary in fricatives and laterals often prohibit it. Therefore flapping out could be treated as an additional property of retroflexes.

An alternative way of defining retroflexes by articulatory properties that takes into account the points of criticism is presented in table 7.1.

Table 7.1 Alternative to the defining properties used in the present dissertation with 6 properties instead of 4 and a manner-specific application. A plus indicates that the specific manner has to have this property in order to be considered retroflex, a minus that it does not, and a question mark indicates that this cannot be decided on without further research.

property	stops	fricatives	nasals etc.
apicality	+	+	+
posteriority	+	–	?
sublingual cavity	+	+	+
retraction	?	+	?
flatness	?	+	?
flapping out	+	–	?

The system in table 7.1 is a suggestion for a possible improvement of the four articulatory characteristics proposed and used in the present dissertation. Further research is necessary to provide the details that are still missing in this system and to show whether this proposal is indeed superior to the system used in the chapters above.

Besides the four articulatory properties, two perceptual characteristics for the class of retroflexes were proposed in chapter 3, namely a mid or high F2, which defines them as being coronal, and, more importantly, a low F3, which distinguishes them from all other coronals. These cues have only relative values, thus a mid or high F2 of coronals contrasts with a low F2 of labials and velars, and a low F3 of retroflexes contrasts with a high F3 of non-retroflex coronals. Exact formant values for specific languages were ignored since the aim was, just as in the case of the articulatory properties, to find general properties that hold cross-linguistically. For language-specific descriptions, however, precise values have to be established, see section 7.3 below.

7.2 Phonological representations of retroflex processes

Retroflexes can umdergo a number of phonological processes that are grounded in the articulatory and acoustic characteristics of this class as defined above in 7.1. These processes, discussed in chapter 4, are repeated here in (4).

(4)	*input*	*output*	*process*
(a)	/rt/	[ʈ]	retroflexion in rhotic context
(b)	/ut/	[uʈ]	retroflexion in back vowel context
(c)	/iʈ/	[it] or [ɨʈ]	deretroflexion or vowel retraction
	/$ʈ^{j}$/	[t^{j}] or [ʈ]	deretroflexion or depalatalization
(d)	/Vʈ/	[$V^{ʈ}$ʈ]	retroflexion of adjacent vowel
(e)	/ʈ/	($_{ω}$[t], C[t]	phonotactic restrictions on retroflexes
(f)	/ʈt/	[ʈʈ]	local assimilation of retroflexes
	/ʈVt/	[ʈVʈ]	non-local assimilation of retroflexes

Chapter 4 illustrated that deretroflexion and depalatalization, see (4c), and retroflexion of adjacent vowels, see (4d), have an exclusively articulatory motivation, by saving a gesture or avoiding the costful synchronizing of two gestures. The larger number of these processes, however, makes a perceptual licensing of such gestural changes necessary, i.e. the output has to be perceptually very close to the input or has to be less distinguishable from the input in the context of occurrence. This is the case for retroflexion in rhotic context, see (4a), for retroflexion in back vowel context (4b), and for phonotactic restrictions and assimilations of retroflexes, see (4e) and (4f), respectively.

A phonological representation of the processes in (4) therefore has to take their phonetic groundings into account. It was illustrated in chapter 5 that traditional featural approaches do not meet these requirements for several reasons. It was argued that these approaches

(i) are (nearly exclusively) based on articulation and thus cannot account for perceptual motivations,

(ii) oversimplify the vocal tract anatomy and the interaction between the articulators, and therefore provide insufficient means to model the interrelations between the tongue parts,

(iii) assume universal phonological features, which are devices to describe cross-linguistic observations, but which are incapable of truly accounting for every phonological process in every language.

Instead of a phonological representation based on articulation only, the account for retroflex processes given in chapter 6 assumes underlying perceptual representations, see Boersma (1998, 2001), from which articulations are derived. This avoids the problem stated under (i) since the proposed approach can account for the perceptual and articulatory motivations of retroflex processes and especially for changes from one articulation to a totally independent one by false association errors such as in the process of retroflexing an apical alveolar after a velar rhotic.

The second point of criticism of previous approaches, i.e., the over-simplification of the vocal tract, cf. (ii), was shown to be particularly problematic for an account of the incompatibility of retroflexes with palatalization and front vowel gestures and the resulting deretroflexion, changes of vowel, or palatalization, cf. (4c) above. I proposed a model of four inter-related tongue parts, repeated here in figure 7.1, and in sections 5.4.2 and 6.2 I elaborated the interactions of these tongue parts and how they can account for the incompatibility of retroflexes and high front vowels or glides.

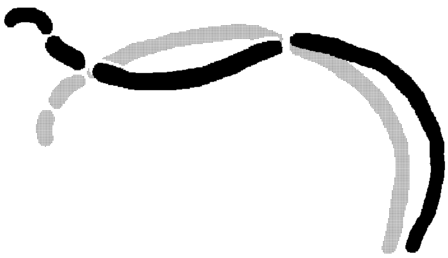

Figure 7.1 A schematic illustration of tongue gestures co-occurring with tongue tip retraction. Underlyingly grey are the tongue parts at rest, from left to right: tip, blade, middle (or pre-dorsum), and back (or post-dorsum) (repeated from figure 2.10).

The model in figure 7.1 is not restricted to retroflex-specific articulatory interrelations. As indicated in 6.4.2, the dependence of tongue blade movements on the movements of the tongue middle can account for complex articulations that can be found in alveolo-palatal or palatal segments, which were problematic for FG accounts with their strict division of tongue blade (CORONAL node) and tongue dorsum (DORSAL node).

With respect to point (iii) of my criticism of traditional approaches, i.e., the universality of phonological features, it was proposed in the present dissertation that there is no need in phonological representations to distinguish between (phonetic) cues and universal phonological features. Instead, the cues that are relevant for phonological processes can be used for the modelling of these processes, thereby making the assumption of an additional, universal feature set redundant. It was argued in chapter 5 that the phonetic basis of features (cues and gestures) renders such a “search for universals” superfluous: What is universal is everything that is based in the articulatory and auditory system of the human, and everything that is based on the capacity of the human to build classes and to generalize.

In terms of the model of language-specific phonologies as represented in figure 1.1 in chapter 1, the use of phonetic cues for language-specific phonological processes, and the abstraction away from these to general features for cross-linguistic descriptions can be depicted as in figure 7.2.

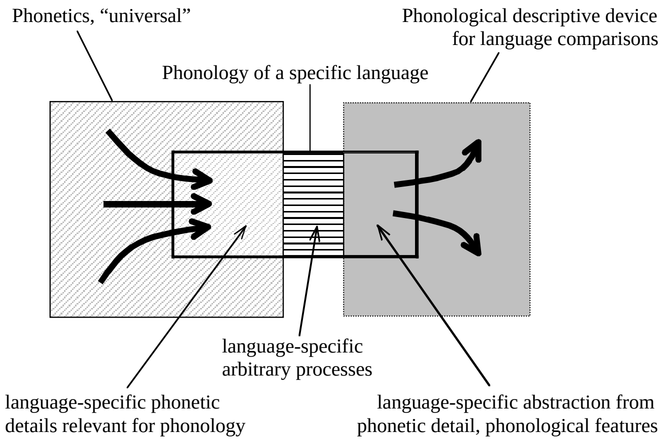

Figure 7.2 Model of phonological knowledge (black box in the middle) as in figure 1.1, plus arrows indicating the direction of influence and abstraction.

The arrows on the left of figure 7.2 indicate the language-specific choice of cues (relevant for the description of the phonological classes and their processes) from the general phonetic space. The arrows on the right illustrate the use of such phonetic cues to explain cross-linguistic variation. The description of cross-linguistic variation is possible by cues that are the intersection of all language-specific features necessary to describe the investigated phonological processes of these languages. This intersection and thus output of generalization differs, depending largely on the phenomena and even more on the languages under investigation. In chapter 6, such general features that abstracted away from language-specific details were used in the form of the unspecified feature [low F3] to describe retroflexes in all languages I looked at. This allowed a cross-linguistic comparison of the processes found and their grounding in the phonetic details.

7.3 Alleged universality of the retroflex class

A question that emerges from the present dissertation and especially from this chapter is why it is necessary to try to find a general, suspiciously universal-looking definition of the class of retroflexes (section 7.1) if at the same time it is stated that universal phonological features and resulting classes do not exist and are furthermore not necessary (section 7.2). This ostensible contradiction can be explained in the following way. The definition of retroflexion proposed and applied in the present dissertation is not based on phonological features, but instead on specific phonetic properties, see section 7.1 above. These properties thus delimit the boundaries of the retroflex class as defined in the present dissertation. Furthermore, exactly these defining properties were shown to account for the similar phonological behaviour of retroflexes across different languages, see chapter 4. The 'universality' of the retroflex class is therefore grounded in its phonetic defining properties.

It is possible to define the retroflex class differently from what has been proposed here, and thus to shift the boundaries of this class. The definition of retroflexes by a bent-backwards tongue tip, for instance, restricts the term retroflex to subapical post-alveolars or palatals, and refers only to a small subgroup of the class I defined as retroflex. Another possibility is to exclude the non-posterior fricative cases such as the Polish post-alveolar (see section 2.4) from the class of retroflexion by defining it as apical or subapical post-alveolar or palatal (see the definition by Catford 1977). Again, this is a feasible approach.

A graphic demonstration of the class boundaries of retroflexion according to these three definitions is given in figure 7.3 on the next page (restricted to coronal sounds and exemplified by fricatives since they yield the largest coronal inventory). This is not meant to be a scale or ordering on any dimension, neither articulatory nor acoustic.

The categories and their boundaries in (a) of figure 7.3 are according to my definition of retroflexion, those in (b) according to definitions which do not include the non-posterior retroflexes (to be found in textbook definitions of retroflexion such as that in Catford 1977), and those in (c) are according to e.g. Ladefoged & Maddieson (1996), who distinguish between an apical and a subapical post-alveolar articulation, only the latter referred to as retroflex.

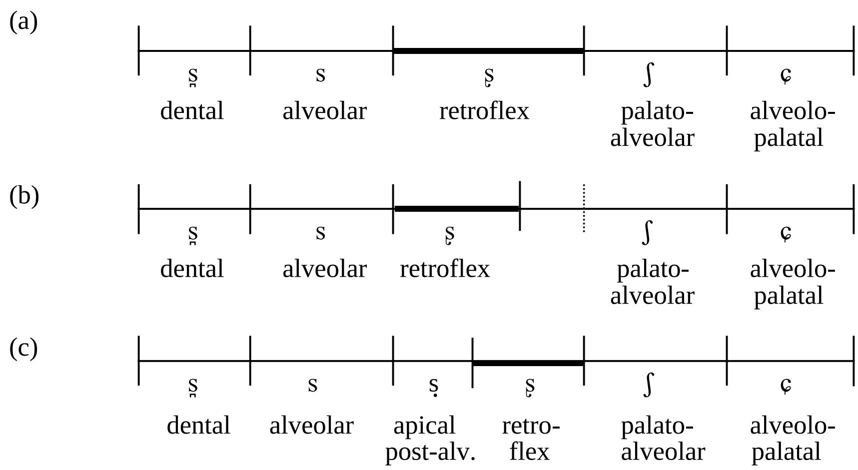

Figure 7.3 Three definitions of retroflex and the resulting category boundaries with the example of fricative inventories.

As can be seen in figure 7.3, the definition applied in the present dissertation (a) yields the largest class of retroflexes, and also includes "marginal" cases of retroflexion such as the non-posterior retroflexes in Polish, Russian, and Mandarin. This broad definition was chosen because it was the aim to describe the space within which languages set their retroflex class (recall figure 1.2 which graphically demonstrated this). Furthermore, this definition was taken because it left the opportunity to test whether even non-prototypical retroflexes share properties and some phonological behaviour with more prototypical ones, thus whether the hypothetic space was correctly delineated, or whether it was too broad. It turned out that the borderlines of the class of retroflexion were correctly chosen since even the borderline cases such as the Polish retroflex were shown to share properties with more prototypical segments of this class (see chapter 4).

The definition of retroflexion as applied here, however, does not imply that all languages with retroflexes need such a broad retroflex category. For language-specific descriptions, the definition of the retroflex category has to be modified according to the inventory, i.e., according to the other segmental classes present in the language under investigation, and the cues associated with these classes. A definition as depicted in (c) in figure 7.3 is for instance useful to describe the fricative system of Toda, which was shown in sections 2.2.6 and 5.2 to have phonetically and phonologically two categories that could be considered retroflex according to my definition. This is is illustrated in figure 7.4.

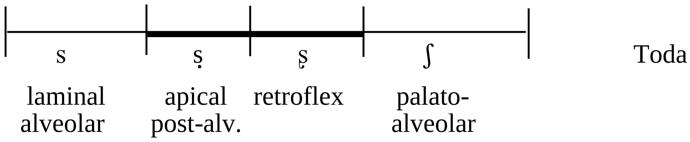

Figure 7.4 Coronal fricative system of Toda with two categories that fall within my definition of retroflex (indicated by the thick black line). A distinction according to Ladefoged & Maddieson's division between apical post-alveolar and subapical post-alveolar/ palatals is possible.

Since Toda systematically distinguishes between the two segment classes that fall within my definition of retroflexes, it follows that such a definition cannot be used for this language. Instead, Ladefoged and Maddieson's distinction of apical post-alveolar (i.e., [s̥]) and subapical post-alveolar or palatal (i.e., [s̢]) seems adequate.

The assumption of language-specific definitions of articulatory classes can, furthermore, account for the fact that languages with small (coronal) inventories allow larger variation of the retroflex class than those with larger inventories (see section 2.2.6). Since the former do not make use of large parts of the phonetic space, this space can be partly occupied by the existing classes, see for instance the example of Norwegian and the Bzyb dialect of Abkhaz in figure 7.5.

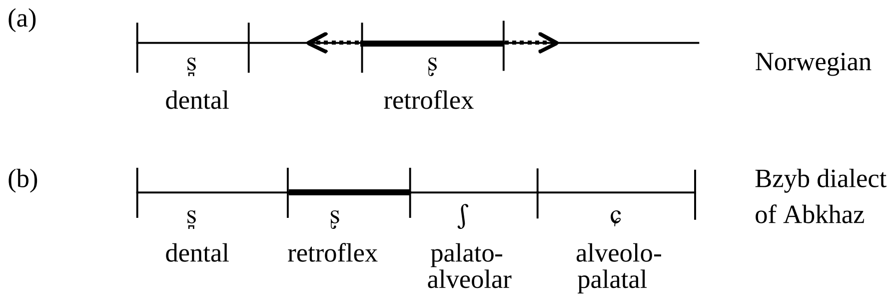

Figure 7.5 Coronal fricative system of Norwegian in (a), with dotted lines indicating the possible articulatory variation, and in the Bzyb dialect of Abkhaz in (b), which has an apical post-alveolar retroflex but does not allow much variation because of its large fricative inventory.

Norwegian has only two coronal fricatives (assuming a variety where the palato-alveolar is totally replaced by the retroflex, recall footnote 41 in chapter 4), the dental [s̪] and the retroflex [ʂ]. This reduced inventory allows large articulatory variation of the retroflex class, as observed by Simonsen et al. (2001), see the indicated variation in figure 7.5 (a). The Bzyb dialect of Abkhaz, on the other hand, has three further coronal fricatives, two of them in the post-alveolar region. This results in a smaller amount of variation and a less posterior articulation of the retroflex class than is evident in other languages.

In this section, only the articulatory characteristics of retroflexes could be shown to vary largely, depending on the language under investigation. A similar variation is assumed to be found for the perceptual cues of retroflexes. Since hardly any study is concerned with the exact perceptual cues of retroflexes and coronals in a particular language, let alone their comparison with what can be found in other languages, this is still an open task. It is expected, however, that despite large variation across languages in their exact values, the perceptual cues of the retroflex class always show a F3 that is far lower than that of any other coronal segmental class.

7.4 Future research

As became obvious from the previous three sections, there are a number of topics that could not be covered in the present thesis but which seem to be of interest for future research.

Concerning the articulatory properties of retroflexes, the more refined model of properties as given in table 7.1 has to be tested, especially with respect to additional manners of retroflexion such as nasals, laterals, and rhotics. The difference between retroflex consonants and retroflex vowels in this respect is another point worthy of further investigation. Most important for the proposed articulatory properties, however, is the search for possible evidence against or further evidence in favour of the property of retraction, in order to either validate or reject the hypothesis that this property is present in all retroflex segments.

The need for language-specific studies on perceptual cues, i.e. the exact values of F3 and F2 for a retroflex class in specific languages, and their comparison was already mentioned above. Such a study could confirm or disconfirm my claim that these perceptual cues also vary greatly from language to language.

With respect to phonological processes involving retroflexes, the list in (4) is not complete; section 4.7 already gave some indications of further processes such as retroflexion of velarized non-retroflexes that seem to be grounded in the phonetics of this class but which could not be studied here. An investigation of their grounding and their phonological modelling seems to be interesting.

Lastly, it remains open for future research to model the phonology of a specific language (and not only with respect to a single segmental class) as closely as possible to the phonetic cues of the segments in these language. The same has to be done for other languages, so that a comparison of these modellings can illustrate the different needs in phonological representations of single languages, and the inadequacy of universal phonological features.

Samenvatting in het Nederlands

In deze dissertatie staat de groep van klinkers en medeklinkers centraal die met de tongpunt tegen de regio achter de tandkassen wordt gearticuleerd. Deze klankgroep, de zogeheten retroflexen, laat een grote articulatorische variatie zien, afhankelijk van factoren zoals spreker, klinker-context, manier van de articulatie, de familie waartoe de taal met retroflexen behoort, en ook het aantal andere (coronale) medeklinkers in de taal.

De parameters van variatie in retroflexen worden geïllustreerd in hoofdstuk twee van deze dissertatie, waar ik ook de vier eigenschappen introduceer voor de definitie van deze klankgroep: apicaliteit, posterioriteit, sublinguale holte en retractie. Niet alle klanken die traditioneel worden beschreven als retroflex laten alle vier de eigenschappen zien. Er is een groep van post-alveolaire fricatieven, zoals die in het Mandarijns Chinees, welke niet posterieur zijn. Bovendien behoren sommige klanken die traditioneel niet als lid van de groep van retroflexen worden gezien, zoals de post-alveolaire fricatieven in het Pools of Russisch, volgens mijn definitie wel tot de retroflexen. Maar ook deze groep mist de eigenschap van posterioriteit. Het is echter alleen het criterium van posterioriteit dat weggelaten kan worden in een retroflexe klank; alle andere criteria moeten aanwezig zijn.

Naast deze herinterpretatie van de definitie van de retroflexen hebben de vier geïntroduceerde eigenschappen nog een consequentie: zij impliceren de onverenigbaarheid van een retroflex met secundaire palatalisering. Ik beargumenteer dat palatalisering van retroflexen resulteert ofwel in een retroflex zonder palatalisering, ofwel in een gepalataliseerde laminale palato-alveolair (een klinker die slechts aan twee criteria voor retroflexie voldoet en dus niet tot de klasse van retroflexen behoort).

De vier articulatorische eigenschappen van retroflexen die hier geïntroduceerd zijn hebben niet de status van fonologische kenmerken met binaire waarden. Ze beschrijven alleen de articulatorische realisatie van de retroflexe klasse. Voor een fonologische beschrijving introduceer ik kenmerken gebaseerd op de akoestische eigenschappen van deze groep klanken. In hoofdstuk drie worden deze akoestische eigenschappen van retroflexen in detail geïllustreerd. Hier wordt duidelijk dat alle retroflexen een lage derde formant hebben (ook als de exacte hoogte van deze formant varieert en niet altijd even laag is vergeleken met de hoge derde formant van palato-alveolaire klanken). Om deze reden gebruik ik deze lage derde formant als het fonologische kenmerk [-2F3], dat alle retroflexen karakteriseert.

Hoofdstuk drie bespreekt verder de notie van ‘weak cues’, die soms wordt gebruikt voor retroflexe klanken. Ik beargumenteer dat retroflexen geen zwakkere akoestische eigenschappen hebben dan alle andere klankgroepen.

In hoofdstuk vier worden fonologische eigenschappen van retroflexen beschreven die niet afhankelijk zijn van taalfamilie maar die desondanks gevonden kunnen worden in veel talen met retroflexen. De fonologische processen zijn retroflexering in de context van r-klanken en achter-klinkers, de-retroflexering in de context van voor-klinkers, retroflexering van klinkers, fonotactische beperkingen op retroflexen, en assimilatieprocessen van retroflexen. In hoofdstuk vier toon ik aan dat de vier articulatorische eigenschappen die samen met de akoestische eigenschap de retroflexe klasse definiëren, verantwoordelijk zijn voor dit homogene fonologische gedrag: de processen zijn gebaseerd op en kunnen worden verklaard door deze gemeenschappelijke eigenschappen, dat wil zeggen de fonologische processen zijn gebaseerd ('grounded') in hun fonetische kenmerken.

In tegenstelling tot traditionele fonologische theorieën, stel ik voor dat de groep van retroflexe klanken en de fonologische processen waarin ze betrokken zijn kunnen worden gerepresenteerd door akoestische kenmerken. Hoofdstuk vijf geeft een overzicht van traditionele representaties van retroflexen met articulatorische kenmerken en hun zwakke punten. Het hoofdstuk beschrijft verder nieuwere benaderingen in de fonologie die akoestische informatie representeren in fonologische modellen.

Een fonologische analyse van de retroflexe processen uit hoofdstuk vier met akoestische kenmerken voor de retroflexe klasse wordt gegeven in hoofdstuk zes, gebaseerd op het 'functional phonology' model van Paul Boersma.

Ik kom tot de slotconclusie dat er geen universele klasse van retroflexen is die met aangeboren fonologische features behoeft te worden beschreven. Desalniettemin gebruiken veel talen een klasse die aan min of meer de vier articulatorische eigenschappen van retroflexen voldoet, en die daardoor ook vergelijkbare fonologische processen vertonen.

Curriculum Vitae

Silke Hamann was born in Lampertheim (Germany) on February 25th, 1971. She finished high school in Heppenheim in 1990 and studied architecture in Weimar in 1991/1992. Hereafter, she studied English literature, sociology, and general linguistics in Frankfurt, Manchester, and Berlin, and obtained her Master's degree in linguistics and English literature in Berlin in 1998.

From 1999 until 2002 Silke held a position as a PhD researcher at the Utrecht Institute of Linguistics OTS, and worked from January until September 1999 and from August 2001 until December 2002 as a scientific researcher at the Centre for General Linguistics (ZAS) in Berlin. The present dissertation is the result of her research at both institutes.

In January 2003 Silke started working as a post-doc researcher at the ZAS Berlin for the DFG project "manner changes in phonology".

References

References containing the indication *ROA* are available online at the Rutgers Optimality Archive, http://roa.rutgers.edu/.

Ahmed, Rais & S.S. Agrawal (1969) "Significant Features in the Perception of (Hindi) Consonants." *Journal of the Acoustical Society of America* 45,3: 758-763.

Allen, William S. (1951) "Some prosodic aspects of retroflexion and aspiration in Sanskrit." *Bulletin of the School of Oriental and African Studies* 13.4; 939-946.

Allen, William S. (1953) *Phonetics in ancient India*. London: Oxford University Press.

Allen, William S. (1954) "Retroflexion in Sanskrit: prosodic technique and its relevance to comparative statement." *Bulletin of the School of Oriental and African Studies* 16.3; 556-565.

Allen, William S. (1962) *Sandhi: the theoretical, phonetic, and historical bases of word-junction in Sanksrit*. 'S-Gravenhage: Mouton

Andersen, Henning (1968) "IE *s after i, u, r, k in Baltic and Slavic." *Acta Linguistics Hafniensia* 11: 171-190.

Anderson, Stephen R. (1985) *Phonology in the Twentieth Century: Theories of Rules and Theories of Representations*. Chicago: Chicago University Press.

Anderson, Viktoria B. & Ian Maddieson (1994) "Acoustic characteristics of Tiwi coronal stops." *UCLA Working Papers in Phonetics* 87: 131-162.

Anttila, Arto (1995) *Deriving variation from grammar: A study of Finnish genitives*. Manuscript, Stanford University. ROA 63.

Archangeli, Diana (1988) "Aspects of underspecification theory." *Phonology* 5: 183-207.

Archangeli, Diana & Douglas Pulleyblank (1994) *Grounded Phonology*. Cambridge (Mass.): MIT Press.

Avery, Peter & Keren Rice (1989) "Segment Structure and Coronal Underspecification." *Phonology* 6: 179-200.

Bailey, T. Grahame (1937) *The pronunciation of Kashmiri*. London: Royal Asiatic Society.

Balasubramanian, R. (1972) *The Phonetics of Colloquial Tamil*. PhD thesis, Edinburgh.

Balasubramanian, T. (1982) "The two r's and the two n's in Tamil." *Journal of Phonetics* 10: 89-97.

Ball, Martin & Joan Rahilly (1999) *Phonetics: The Science of Speech*. London: Arnold.

Beck, Janet Mackenzie (1997) "Organic Variation of the Vocal Apparatus." In: W.J. Hardcastle & J. Laver (eds) *The Handbook of Phonetic Sciences*. Oxford: Blackwell; 256-297.

Beckman, Jil (1998) *Positional Faithfulness*. Dissertation manuscript, University of Massachusetts, Amherst.

Bermúdez-Otero, Ricardo (1996) "Stress and quantity in Old and early Middle English: evidence for an optimality-theoretic model of language change." Manuscript University of Manchester. ROA 136.

Bhat, D.N.S. (1973) "Retroflexion: An Areal Feature." *Working Papers on Language Universals* 13: 27-67.

Bhat, D.N.S. (1974a) "Retroflexion and Retraction." *Journal of Phonetics* 2: 233-237.

Bhat, D.N.S. (1974b) "A general study of palatalisation." *Working Papers on Language Universals* 14; 47-92.

Bhat, Roopkrishen (1987) *A descriptive study of Kashmiri*. Delhi: Amar Prakashan.

Bhatia, Tej K. (1993) *Punjabi: A cognitive descriptive grammar*. London: Routledge.

Biedrzycki, Leszek (1974) *Abriß der polnischen Phonetik.* Warszawa: Wiedza Powszechna.

Blake, Barry J. (1979) "Pitta-Pitta." In: R.M.W. Dixon & B. Blake (eds.); 183-242.

Blake, Barry J. & John Gavan Breen (1971) *The Pitta-Pitta dialects*. Melbourne: Monash University.

Blankenship, Barbara, Peter Ladefoged, Peri Bhaskararao & Nichumeno Chase (1993) "Phonetic Structures of Khonoma Angami." *UCLA Working Papers in Phonetics* 84: 127-142.

Boersma, Paul (1998) *Functional Phonology: Formalizing the interaction between articulatory and perceptual drives*. The Hague: Holland Academic Graphics.

Boersma, Paul (1999) "On the need for a separate perception grammar:" In: R. Kirchner, W. Wikeley & J. Pater (eds.) *Papers in Experimental and Theoretical Linguistics*. Volume 5. Edmonton: University of Alberta.

Boersma, Paul (2003a) "The odds of eternal optimization in OT." In: Eric Holt (ed.) *Optimality Theory and Language Change*. Dordrecht: Kluwer; 31-65.

Boersma, Paul (2003b) "Nasal harmony in functional phonology." In: J. v.d. Weijer, H. v.d. Hulst & V.v. Heuven (eds.) *The phonological spectrum*, Vol. 1: *Segmental structure*. Amsterdam: John Benjamins; 3-35

Bolla, Kálmán (1981) *A Conspectus of Russian Speech Sounds*. Budapest: Hungarian Academy of Science.

Booij, Gert & Jerzy Rubach (1987) "Postcyclic versus Postlexical Rules in Lexical Phonology." *Linguistic Inquiry* 18: 1-44.

Borgstrøm, C.H. (1940) "A linguistic survey of the Gaelic dialects of Scotland, vol. I: The dialects of the outer Hebrids." *Norsk Tidsskrift for Sprogvidenskap*. Suppl. Bind I. Oslo: Aschehoug.

Bradley, John (1980) "Acoustic correlates of seven consonantal positions in Yanyuwa." *University of Melbourne Working Papers in Linguistics* 6: 21-48.

Breen, John Gavan (1981) "Margany and Gunya." In: R.M.W. Dixon & B. Blake (eds.); 275-392.

Bright, William O. (1957) *The Karok language*. Berkeley: Univ. of California Press.

Bright, William O. (1975) "The Dravidian Enunciative Vowels." In: H. Schiffman & C. Eastman (eds.) *Dravidian phonological systems*. Seattle: University of Washington; 11-46.

Brosnahan, L.F. & Bertil Malmberg (1970) *Introduction to Phonetics*. Cambridge: Heffer & Sons.

Browman, Catherine & Louis Goldstein (1989) "Articulatory gestures as phonological units." *Phonology* 6: 201-251.

Browman, Catherine & Louis Goldstein (1992) "Articulatory phonology: an overview." *Phonetica* 49: 155-180.

Burrow, Thomas (1955) *The Sanskrit language*. London: Faber and Faber.

Busby, Peter Andres (1979) *A classificatory study of phonemic systems in Australian Aboriginal languages*. Manuscript (M.A. thesis), Australian National University.

Butcher, Andrew (1992) "The phonetics of neutralisation: the case of Australian coronals." In: Jack Windson (ed.) *Studies in general and English phonetics*. London: Routledge; 10-38.

Butcher, Andrew (1995) *The Phonetics of Australian languages*. Oxford: Oxford University Press.

Bybee, Joan (1999) "Usage-based Phonology." In: M. Darnell et.al. (eds.); 211-242.

Calabrese, Andrea (1988) "Towards a Theory of phonological alphabets." Ph.D. dissertation, Massachusetts Institute of Technology.

Catford, John C. (1970) "Articulatory possibilities of man." In: Malmberg (ed.); 309-333.

Catford, John C. (1977) *Fundamental Problems in Phonetics*.Edinburgh: University Press.

Catford, John C. (1988) *A Practical Introduction to Phonetics*. Oxford: Clarendon Press.

Catford, John C. (1994) "Articulatory Phonetics." In: Ronald Asher (ed.) *The Encyclopaedia of Language and Linguistics*. Oxford: Pergamon Press; 3058-3070.

Ćavar, Małgorzata & Silke Hamann (2002) "Polish velar and coronal palatalization – its perceptual background." Ms. to be published in *Proceedings of the Fourth European Conference on Formal Description of Slavic Languages* (FDSL-4)

Chao, Y. R. (1948) *Mandarin Primer*. Cambridge (Mass.): Harvard University Press.

Chao, Y. R. (1968) *A Grammar of spoken Chinese*. Berkeley: University of California Press.

Cho, Young-Mee (1991) "On the Universality of the Coronal Articulator." In: Paradis & Prunet (eds.); 159-179.

Chomsky, Noam & Morris Halle (1968) *The Sound Pattern of English*. New York: Harper and Row.

Christdas, Prathima (1988) *The Phonology and Morphology of Tamil*. Ann Arbour: UMI.

Clements, George N. (1985) "The Geometry of Phonological Features." *Phonology Yearbook* 2: 225-252.

Clements, George N. (1991) "Place of articulation in consonants and vowels: a unified theory." *Working Papers of the Cornell Phonetics Laboratory* 5: 77-123.

Clements, George N. (2001) "Representational economy in constraint-based phonology." T. Hall (ed.) *Distinctive feature theory*. Berlin: Mouton de Gruyter; 71- 146.

Clements, G. Nick & Elizabeth Hume (1995) "The Internal Organization of Speech Sounds." In: J. Goldsmith (ed); 245-306.

Connell, Bruce & Amalia Arvaniti (eds.) *Phonology and phonetic evidence: Papers in laboratory phonology IV*. Cambridge: Cambridge University Press, 1995.

Crowley, Terry (1981) "Anguthimiri (the Mpakwithi Dialect)." In: R.M.W. Dixon & Barry Blake (eds.); 147-196.

Crowley, Terry (1983) "Uradhi." R.M.W. Dixon & Barry Blake (eds.); 309-416

Darnell, Michael, Edith Moravcsik, Frederick Newmeyer, Michael Noonan & Kathleen Wheatley (eds.) *Functionalism and Formalism in Linguistics*. Volume 1: general papers. Amsterdam: John Benjamins, 1999.

Dart, Sarah (1991) "Articulatory and Acoustic Properties of Apical and Laminal Articulations." *UCLA Working Papers in Phonetics* 79: 1-155.

Dart, Sarah & Paroo Nihalani (1999) "The articulation of Malayalam coronal stops and nasals." *Journal of the International Phonetic Association* 29,2: 129-142.

Dave, Radhekant (1977) "Retroflex and dental consonants in Gujarati: a palatographic and acoustic study." *Annual Report of the Institute of Phonetics, University of Copenhagen* (*ARIPUC*) 11: 27-156.

Davis, Stuart (1991) "Coronals and the Phonotactics of Nonadjacent Consonants in English." In: C. Paradis & J.-F. Prunet (eds.); 49-60.

De Jong, Kenneth (1995) "On the status of redundant features: the case of backing and rounding in American English." In: B. Connell & A. Arvaniti (eds.); 68-86.

Diffloth, Gerard (1975) "The south Dravidian obstruent system in Irula." In H. Schiffman & C. Eastman (eds.) *Dravidian phonological systems*. Seattle: University of Washington; 47-56.

Dixit, R. Prakash (1990) "Linguotectal contact patterns in the dental and retroflex stops of Hindi." *Journal of Phonetics* 18: 189-201.

Dixit, R. Prakash & James Flege (1991) "Vowel Context, Rate and Loudness Effects of Linguopalatal Contact Patterns in Hindi Retroflex /long-legged t/." *Journal of Phonetics* 19.2: 213-229.

Dixon, R.M.W. (1980) *The Languages of Australia*. Cambridge: Cambridge University Press.

Dixon, R.M.W. & Barry Blake (eds.) *Handbook of Australian languages. Volume II*. Amsterdam: Benjamins, 1981.

Dixon, R.M.W. & Barry Blake (eds.) *Handbook of Australian languages. Volume III*. Amsterdam: Benjamins, 1983.

Dixon, R.M.W. & Barry Blake (eds.) *Handbook of Australian languages. Volume IV*. Oxford: Oxford University Press, 1991.

Dixon, R.M.W. & Barry Blake (eds.) *Handbook of Australian languages. Volume V*. Oxford: Oxford University Press, 2000.

Docherty, Gerard J. & D. Robert Ladd (eds.) *Papers in Laboratory Phonology*. Cambridge: Cambridge University Press, 1992.

Dogil, Grzegorz (1990) *Hissing and Hushing Fricatives: A Comment on non-anterior Spirants in Polish*. Manuscript, Stuttgart University.

Dommelen, Wim van (2001) "Teenagers' pronunciation of Norwegian /ç/ and /ʃ/." *Lund University Working Papers* 49: 22-25.

Donaldson, Tamsin (1980) *Ngiyamba*. Cambridge: Cambridge University Press.

Ebert, Karen (1996) *Kodava*. Muenchen: Lincom Europa.

Edelman, Dzoj I. (1983) *The Dardic and Nuristani languages.* Moscow: Nauka.

Eliasson, Stig (1986) "Sandhi in Peninsular Scandinavian." In: Henning Andersen (ed.) *Sandhi Phenomena in the Languages of Europe*. Berlin: de Gruyter; 271-300.

Emeneau, Murray B. (1939) “The vowels of the Badaga language.” *Language* 15 (1); 43-47.
Emeneau, Murray B. (1970) *Dravidian Comparative Phonology: A Sketch*. Annamalainagar: Annamalai University.
Emeneau, Murray B. (1984) *Toda Grammar and Texts*. Philadelphia: American Philosophical Society.
Endresen, R.T. (1974) “On Retroflex Segments in Norwegian.” *Norwegian Journal of Linguistics* 28: 73-78.
Evans, Nickolas (1985) *Kayardild: the language of the Bentick Islanders of North West Queensland*. Ph.D. dissertation, Australian National University.
Evans, Nickolas (1995) “Current Issues in the Phonology of Australian Languages.” In: J. Goldsmith (ed.); 723-740.
Fant, Gunnar (1974) *Speech Sounds and Features*. Cambridge: MIT Press.
Ferguson, Charles A. (1960) *Linguistic diversity in South Asia: studies in regional, social and functional variation*. Bloomington (Ind.): Research Center at Indiana University.
Flemming, Edward (1995) *Auditory Representations in Phonology*. Dissertation UCLA.
Flemming, Edward (1997) “Phonetic detail in phonology: Towards a unified account of assimilation and coarticulation.” In: K. Suzuki and D. Elzinga (eds.) *Proceedings of the 1995 Southwestern Workshop in Optimality Theory (SWOT)*, University of Arizona.
Flemming, Edward (2002) *Auditory Representations in Phonology*. Routledge: London.
Fougeron, Cécile (1999) “Prosodically conditioned articulatory variation: A review.” *UCLA Working Papers in Phonetics* 87; 1-73.
Fowler, Carol A. (1994) “Invariants, specifiers, cues: an investigation of locus equation as information for place of articulation.” *Perception and Psychophysics* 55: 597-610.
Gair, James W. & John C. Paolillo (1997) *Sinhala.* Unterschleissheim: Lincom.
Gnanadesikan, Amalia (1993) “The Feature Geometry of Coronal Subplaces.” *University of Massachusetts Occasional Papers in Lingiustics* 16: 27-67.
Gnanadesikan, Amalia (1994) ”The Geometry of Coronal Articulations.” *Proceedings of the North East Linguistics Society* 24,1: 125-139.
Goeman, Ton & Hans Van de Velde (1999) “Co-occurrence constraints on /r/ and /ɣ/ in Dutch dialects.” In: H. v. d. Velde & R. v. Hout (eds.); 91-112.
Goldsmith, John (1976) *Autosegmental phonology*. Ph.D. manuscript, Cambridge: Massachusetts Institute of Technology.
Goldsmith, John (ed.) *The Handbook of Phonological Theory.* Cambridge: Blackwell, 1995.
Greenberg, Joseph H. (1978) “Some generalizations concerning initial and final consonant clusters.” In: J. Greenberg (ed.) *Universals of Human Language. Volume 2: Phonology.* Stanford: Stanford University Press; 243-279.
Grierson, George (1911) *Standard manual of the Kashmiri language.* 2 volumes. Jammu: Light and Life.
Gussenhoven, Carlos & Haike Jakobs (1998) *Understanding Phonology*. London: Arnold.
Hagiwara, Robert (1995) “Acoustic realizations of American /r/ as produced by women and men.” *UCLA Working Papers in Phonetics* 90.
Hall, T. Alan (1997a) *The Phonology of Coronals*. Amsterdam: John Benjamins.
Hall, T. Alan (1997b) “The Historical Development of Retroflex Consonants in Indo-Aryan.” *Lingua* 102: 203-221.
Hall, T. Alan (2000) “Typological generalizations concerning secondary palatalization.” *Lingua* 110: 1-25.
Halle, Morris (1992) “Phonological Features.” In: W. Bright (ed.) *Oxford International Encyclopedia of Linguistics*. Oxford; 207-212.
Halle, Morris & Kenneth Stevens (1969) “On the feature ‘advanced tongue root’.” *Quarterly Progress Report 94.* Cambridge, MA: Research Laboratory of Electronics, MIT, 209-215.
Halle, Morris & Kenneth Stevens (1997) “The postalveolar fricatives of Polish.” In: S. Kiritani, H. Hirose & H. Fujisaki (eds.). *Speech Production and Language: In Honor of Osamu Fujimura*. Berlin. Mouton de Gruyter; 177-193.
Hamann, Silke (2002a) “Retroflexion and Retraction revised.” In: T.A. Hall, B. Pompino-Marschall & M. Rochoń (eds.) *ZAS working papers* 28: 13-25.

Hamann, Silke (2002b) "Postalveolar Fricatives in Slavic Languages as Retroflexes." In: S. Baauw, M. Huiskes & M. Schoorlemmer (eds.) *OTS Yearbook 2002*. Utrecht: Utrecht Institute of Linguistics; 105-127.

Hamann, Silke (2003) "Is retroflexion licensed by VC cues only? Observations from Norwegian." Ms. to be published in P. Svevonius (ed.) *Proceedings of the 19th Scandinavian Conference of Linguistics.*

Hamilton, Philip James (1993) "On the Internal Structure of the Coronal Node." *ESCOL* 93: 129-140.

Hamilton, Philip James (1996) *Phonetic constraints and markedness in the phonotactics of Australian Aboriginal languages.* Toronto: University of Toronto.

Harris, John (1994) *English sound structure*. Oxford: Blackwell.

Harrison, Sheldon (1995) "Ponapean." In: D. Tryon, M. Ross, et al. (eds.) *Comparative Austronesian Dictionary: An Introduction*. Berlin: Mouton de Gruyter, 905-912.

Heike, Georg (1982) *Phonologie.* Stuttgart: Metzler.

Heath, Jeffrey (1980) *Basic materials in Ritharngu: grammar, texts, and dictionary*. Canberra: Australian National University.

Hercus, Luise A. (1986) *Viktorian languages: a late survey*. Canberra: Australian National University.

Himmelmann, N.P. (1991) "Tonini-Tolitoli sound structures." In: James Sneddon (ed.) *Studies in Sulawesi Linguistics II*. Jakarta: Nusa; 49-70.

Hudson, Joyce & Eirlys Richards (1969) "The phonology of Walmatjari." *Oceanic Linguistics* 8: 171-189.

Hume, Elizabeth (1994) *Front Vowels, Coronal Consonants and their Interaction in Nonlinear Phonology*. London: Garland.

Hume, Elizabeth & Keith Johnson (2001) *Phonology: The Role of Speech Perception in Phonology*. San Diego, CA: Academic Press.

Hume, Elizabeth & Georgios Tserdanelis (2002) "Labial unmarkedness in Sri Lankan Portuguese Creole." Manuscript, Ohio State University. ROA 545.

Hunter, G.G. & E.V. Pike (1969) "Phonology of tone sandhi of Molinos Mixtec." *Linguistics* 47: 24-40.

Hyman, Larry (1973) "The Feature [grave] in Phonological Theory." *Journal of Phonetics* 1: 329-337.

Iverson, Gregory K. & M. L. Oñderra (1985) "On Basque Palatalization." *Folia Linguistica* 19: 51-61.

Jakobson, Roman, Gunnar Fant & Morris Halle (1952) *Preliminaries to Speech Analysis: The Distinctive Features and their Correlates*. Cambridge (Mass.): MIT Press.

Jakobson, Roman & Morris Halle (1956) *Fundamentals of Language*. The Hague: Mouton.

Jassem, Wiktor (1979) "Classification of Fricative Spectra using Statistical Discrimant Functions." In: B. Lindblom & S. Öhman (eds.) *Frontiers of Speech Communication Research*. New York: Academic Press; 77-91.

Johnson, Keith (1997) *Acoustic and Auditory Phonetics*. Oxford: Blackwell.

Jones, Daniel & Dennis Ward (1969) *The Phonetics of Russian*. Cambridge: Cambridge University Press.

Jun, Jongho (1995) "Place assimilation as the result of conflicting perceptual and articulatory constraints." *West Coast Conference on Formal Linguistics* 14.

Karunatillake, W.S. (1992) *An Introduction to spoken Sinhala*.

Keating, Patricia A. (1991) "Coronal Places of Articulation." In: C. Paradis & J.-F. Prunet (eds.), 29-48.

Kehrein, Wolfgang (2002) *Phonological Representation and Phonetic Phasing*. Tuebingen: Max Niemeyer Verlag.

Kelkar, Ashok R. & Pran Nath Trisal (1964) "Kashmiri Word Phonology: A First Sketch." *Anthropological Linguistics* 6,1: 13-22.

Kingston, John & Mary Beckman (eds.) *Papers in Laboratory Phonology I: Between the Grammar and Physics of Speech*. Cambridge: Cambridge University Press. 1990.

Kingston, John & Randy L. Diehl (1994) "Phonetic knowledge." *Language* 70,3: 419-454.

Kingston, John & Randy L. Diehl (1995) "Intermediate properties in the perception of distinctive feature values." In: B. Connell & A. Arvaniti (eds.); 7-27.

Kirchner, Robert (1997) "Contrastiveness and Faithfulness." *Phonology* 14.1: 83-111.

Krakow, Rena (1999) "Physiological organization of syllables: a review." *Journal of Phonetics* 27: 23-54.

Krauss, Michael E. (1973) "Na-Dené." In T. Sebeok (ed.), *Linguistics in North America*. Current Trends in Linguistics Vol. 10. The Hague: Mouton.

Krauss, Michael E. (1979) "Na-Dené and Eskimo-Aleut." in L. Campbell & M. Mithun (eds.) *The Languages of Native North America: An Historical and Comparative Assessment*. Austin: University of Texas Press; 803-901.

Kristoffersen, Gjert (2000) *The Phonology of Norwegian*. Oxford: Oxford University Press.

Krull, Diana (1990) "Relating acoustic properties to perceptual responses: A study of Swedish voiced stops." *Journal of the Acoustical Society of America* 88,6: 2557-2570.

Krull, Diana, Björn Lindblom, B.-E. Shia & D. Fruchter (1995) "Crosslinguistic Aspects of Coarticulation: An Acoustic and Electropalatographic Study of Dental and Retroflex Consonants." *Proceedings of the XIIIth International Congress of Phonetic Sciences* (Stockholm).Volume 4: 436-439.

Ladefoged, Peter (1964) *A Phonetic Study of West African Languages: An Auditory-Instrumental Survey*. Cambridge: Cambridge University Press.

Ladefoged, Peter (1971) *Preliminaries to Linguistic Phonetics*. Chicago: UCP.

Ladefoged, Peter (1975) *A Course in Phonetics*. New York: Harcourt Brace Jovanovich. 2nd ed. 1982.

Ladefoged, Peter (1994) "The links between theory and fieldwork in phonetics." *UCLA Working Papers in Phonetics* 88: 13-28.

Ladefoged, Peter (2001) *Vowels and consonants: An introduction to the sounds of languages*. Oxford: Blackwell.

Ladefoged, Peter & Ian Maddieson (1986) "Some of the Sounds of the World's Languages: preliminary version." *UCLA Working Papers in Phonetics* 64.

Ladefoged, Peter & Ian Maddieson (1996) *The Sounds of the World's Languages*. Oxford: Blackwell.

Ladefoged, Peter & Peri Bhaskararao (1983) "Non-quantal Aspects of Consonant Production: A Study of Retroflex Consonants." *Journal of Phonetics* 11: 291-302.

Ladefoged, Peter & Zongji Wu (1984) "Places of Articulation: An Investigation of Pekingese Fricatives and Affricates." *Journal of Phonetics* 12: 267-278.

Ladefoged, Peter, A. Cochran & S. Disner (1977) "Laterals and trills." *Journal of the International Phonetic Association* 7: 46-54.

Lahiri, Aditi & Sheila E. Blumstein (1984) "A re-evaluation of the feature Coronal." *Journal of Phonetics* 12,2: 133-146.

Laver, John (1994) *Principles of Phonetics*. Cambridge: Cambridge University Press.

Lee, Wai-Sum (1999) "An articulatory and acoustical analysis of the syllable-initial sibilants and approximants in Beijing Mandarin." *Proceedings of the International Congress on Phonetic Sciences 1999*, San Francisco, 413-416.

Lin, Yen-Hwei (1989) "The Retroflex as a Complex Segment." *ESCOL* 6: 182-193.

Lindau, Mona (1985) "The story of /r/." In: Victoria Fromkin (ed.) *Phonetic Linguistics: Essays in Honour of Peter Ladefoged*. Orlando (Fl.): Academic Press; 157-168.

Lindau, Mona & Peter Ladefoged (1986) "Variability of feature specification." In: J.S. Perkell & D.H. Klatt (eds.) *Invariance and Variability in Speech Processes*. Hillsdale: Erlbaum; 465-478.

Lindblad, Per (1980) "Svenskans sje- och tje-ljud i ett allmänfonetisk perspektiv." *Travaux de l'Institut de Linguistique de Lund 16*, Lund: Gleerup.

Lindblad, Per & Sture Lundqvist (1994) "The Production of Swedish Sibilants – an EPG Analysis." *Working Papers of the Lund University Department of Linguistics and Phonetics* 43: 88-91.

Lindblad, Per & Sture Lundqvist (1997) "The production of coronals in hyper- and hypospeech." *Phonum* 4: 29-33.

Lindblad, Per & Sture Lundqvist (1999) "How and why do the tongue gestures of [t], [d], [l], [n], [s], and [r] differ?" *Proceedings of the International Congress on Phonetic Sciences 1999*, San Francisco, 417-420.

Lindblom, Björn (1986) "Phonetic universals in vowel systems." In: J.J. Ohala & J.J. Jaeger (eds.) *Experimental Phonology*. Orlando: Academic Press; 13-44.

Lindblom, Björn & Johan Sundberg (1971) "Acoustical consequences of lip, tongue, jaw, and larynx movement." *Journal of the Acoustical Society of America* 50,4 (2): 1166-1179.

Lobacz, Piotra (1996) *Polska fonologia dziecięca.* Warszawa: Energeia.

Löhken, Sylvia C. (1997) *Deutsche Wortprosodie: Abschwächungs- und Tilgungsvorgänge*. Studien zur deutschen Grammatik 56, Tübingen: Stauffenburg Verlag.

Lombardi, Linda (1995) "Laryngeal neutralization and syllable wellformedness." *Natural Language and Linguistic Theory* 13: 39-74.

Maddieson, Ian (1984) *Patterns of Sounds*. Cambridge: Cambridge University Press.

Maddieson, Ian (1986) "The size and structure of phonological inventories: Analysis of UPSID." In: J. Ohala & J. Jaeger (eds.) *Experimental Phonology*. Orlando (Fl.): Academic Press; 105-123.

Masica, Colin (1991) *The Indo-Aryan languages*. Cambridge: Cambridge University Press.

Mayrhofer, Manfred (1989) "Vorgeschichte." In: R. Schmitt (ed.); 4-24.

McCarthy, John (1988) "Feature geometry and dependency: a review." *Phonetica* 43: 84-108.

McCarthy, John & Alan Prince (1993) *Prosodic morphology I: Constraint interaction and satisfaction*. Manuscript, University of Massachusetts and Rutgers University.

McCarthy, John & Alan Prince (1995) "Faithfulness and reduplicative identity." In: J.Beckmann, S. Urbanczyck, & L. Walsh (eds.) *Papers in Optimality Theory*. University of Massachusetts Occasional Papers in Linguistics 18; 249-384. ROA 60.

McCawley, James (1966) *Further revisions in Finnish rules*. Manuscript, University of Chicago.

McDonald, Maryalyce (1977) "A study of the phonetics and phonology of Yaraldi and associated dialects." M.A. thesis manuscript, Australian National University.

McDonough, Joyce & Keith Johnson (1997) "Tamil liquids: An investigation into the basis of the contrast among five liquids in a dialect of Tamil." *Journal of the International Phonetic Association* 27: 1-26.

McGregor, William (1990) *A functional grammar of Gooniyandi.* Amsterdam: Benjamins.

McKay, Graham (2000) "Ndjébbana." Dixon, R.M.W. & Barry Blake (eds.); 155 – 354.

Miller, Wick R. (1965) *Acoma grammar and texts*. University of California Publications in Linguistics. Berkeley: University of California Press.

Misra, B.G. (1967) "Historical phonology of modern standard Hindi: Proto-Indo European to the present." Ph.D. dissertation, Cornell University.

Morgenstierne, Georg (1927) *An etymological vocabulary of Pashto*. Oslo: J. Dybwad.

Morgenstierne, Georg (1929) "The Language of the Ashkun Kafirs." *Norsk Tidsskrift for Sprogvidenskap* 2: 192.

Morgenstierne, Georg (1941) "The Phonology of Kashmiri." *Acta Orientalia* 19,1: 79-99.

Morphy, Frances (1983) "Djapu, a Yolngu dialect." In: R.M.W. Dixon & B. Blake (eds.); 1-188.

Narayanan, Shrikanth & Abigail Kaun (1999) "Acoustic modeling of Tamil retroflex liquids." *Proceedings of the International Congress on Phonetic Sciences 1999*, San Francisco, 2097-2101.

Nathan, Geoffrey S. (1994) "What Functionalists can learn from Formalists in Phonology." In: Darnell et al. (eds.) Volume 1; 305-327.

Nearey, Terrance M. (1995) "A double-weak view of trading relations: comments on Kingston and Diehl." In: B. Connell & A. Arvaniti (eds.); 28-40.

Newman, Paul (1980) "The two R's in Hausa." *African Language Studies 17*: 77-87.

Odden, David (1978) "Further Evidence for the Feature [grave]." *Linguistic Inquiry* 9: 141-144.

Öhman, S.E.G. (1966) "Perception of Segments of VCCV Utterances." *Journal of the Acoustical Society of America* 40,5: 979-988.

Ohala, John J. (1981) "Speech Timing as a Tool in Phonology." *Phonetica* 38: 204-212.

Ohala, John J. (1985) "Around *Flat*." In: V. Fromkin (ed.) *Phonetic Linguistics: Essays in Honor of Peter Ladefoged*. Orlando etc: Academic Press; 223-241.

Ohala, John J. (1989) "Sound change is drawn from a pool of synchronic variation." In: L. Breivik & E.H. Jahr (eds.) *Language change: contributions to the study of its causes*. Berlin: Mouton; 173-198.

Ohala, John J. (1990) "The phonetics and phonology of aspects of assimilation." In: J. Kingston & M. Beckman (eds.); 258-275.

Ohala, John J. (1992) "Alternatives to the sonority hierarchy for explaining segmental sequential constraints." *Proceedings of the Chicago Linguistic Society* 26,2: 319-338.

Ohala, John J. (1993) "The percetual basis of some sound patterns." In: B.A. Connell & A. Arvaniti (eds.); 87-92.

Ohala, Manjari (1983) *Aspects of Hindi phonology*. Delhi: Motilal Banarsidas.

Ohala, Manjari (1994) "Hindi." *Journal of the International Phonetics Association* 24.1: 35-38.

Ohala, Manjari & John Ohala (2001) "Acoustic VC transitions correlate with degree of perceptual confusion of place contrast in Hindi." N. Grø & J. Rischel (eds.) *Travaux du cercel Linguisticque de Copenhague*. Vol. XXXI. Copenhagen: Reitzel; 265-284.

Ohde, Ralph N. & Donald J. Sharf (1992) *Phonetic Analysis of Normal and Abnormal Speech*. London: Macmillan.

Oliverius, Z. F. (1974) *Fonetika Russkogo Jazyka*. Prague: Státnî Pedagogické Nakladatelstvî.

Padgett, Jaye (2001) "Contrast Dispersion and Russian Palatalization." In: B. Hume & K. Johnson (eds.); 187-218.

Padgett, Jaye (2003) "The emergence of contrastive palatalization in Russian." In: Eric Holt (ed.) *Optimality Theory and Language Change*. Dordrecht: Kluwer; 307-335.

Pandit, P.B. (1954) "Indo-Aryan sibilants in Gujarati." *Indian Linguistics* 14: 503-511.

Papazian, Erik (1994) "Om sje-lyden in norsk, og ombyttina av den med-kje-lyden." *Norskrift* 83: 1-105.

Paradis, Carole & Jean-Francois Prunet (eds.) *The Special Status of Coronals: Internal and External Evidence*. San Diego: Academic Press, 1991.

Passy, Paul (1891) *Etude sur les changements phonétiques et leurs caractères généraux*. Paris: Librairie Firmin-Didot.

Patz, Elisabeth (1991) "Djabugay." In: R.M.W. Dixon & B. Blake (eds.); 244-347.

Payne, John (1989) "Pamir languages." In: R. Schmitt (ed.); 417-444.

Penzl, Herbert (1969) *Geschichtliche deutsche Lautlehre*. Muenchen: Huebner.

Pierrehumbert, Janet (1999) "Formalizing Functionalism." In: M. Darnell et. al. (eds.); 287-304.

Pierrehumbert, Janet, Mary Beckman & D. Robert Ladd (1996) "Laboratory Phonology." In: Jacques Durand & Bernard Laks (eds.) *Current Trends in Phonology: Models and Methods*. Salford: ESRI; 136-149.

Platt, John T. (1972) *An outline grammar of the Gugada dialect: South Australia*. Canberra: AIAS.

Popperwell, Ronald G. (1963) *The pronunciation of Norwegian*. Cambridge: Cambridge University Press.

Prince, A. & P. Smolensky (1993) *Optimality Theory: Constrait Interaction in Generative Grammar*. Brunswick: Rutgers University. ROA 537 (version from 2002).

Prost, G. (1967) "Phonemes of the Chacobo language." *Linguistics* 35: 61-65.

Pulleyblank, Edwin G. (1989) "The Role of Coronal in Articulator Based Features." *Papers from the Chicago Linguistics Society* 25: 279-393.

Recasens, Daniel, Jordi Fontdevila, & Maria Dolors Pallarès (1995) "A production and perceptual acount of palatalization." In: Bruce Connell & Amalia Arvaniti (eds.); 265-281.

Rehg, Kenneth L. (1973) "On the history of Ponapean Phonology." *Working Papers in Linguistics, University of Hawaii*, 5 (8): 17-56.

Rice, Keren (1994) "Peripheral in Consonants." *Canadian Journal of Linguistics* 39: 191-216.

Rubach, Jerzy (1984) *Cyclic and Lexical Phonology. The Structure of Polish*. Dordrecht: Foris.

Rubach, Jerzy (1995) "Representations and the Organization of Rules in Slavic Phonology." In: J. Goldsmith (ed.); 848-866.

Rumsey, Alan (2000) "Bunuba."In: R.M.W. Dixon & B. Blake (eds.); 35-152.

Sagey, Elizabeth C. (1986) *The representation of features and relations in non-linear phonology*. MIT Working Papers in Linguistics, Cambridge (Mas.): MIT.

Sakthivel, Subbiah (1976) *Phonology of Toda with Vocabulary*. Annamalaingar: Sri Velan Press.

Sakthivel, Subbiah (1977) *A Grammar of the Toda Language*. Annamalainagar: Sri Velan Press.

Scatton, Ernest A. (1975) *Bulgarian Phonology*. Columbus: Slavica Publishers.

Schiffman, Harold (1983) *A Reference Grammar of spoken Kannada*. Seattle: University of Washington Press.

Schmitt, Rüdiger (ed.) *Compendium linguarum Iranicum*. Wiesbaden: Reichert, 1989.

Shadle, Christine, C.U. Dobelke & C. Scully (1992) "Spectral Analysis of Fricatives in Vowel Context." *Proceedings J. de Physique IV*; 295-298.

Shalev, Michael, Peter Ladefoged & Peri Bhaskararao (1993) "Phonetics of Toda." *UCLA Working Papers in Phonetics* 84: 89-123.

Sharpe, Margaret (1972) *Alawa phonology and grammar*. Canberra: AIAS.

Simonsen, Hanne G., Inger Moen & Steve Cowen (2000) "Retroflex consonants in Norwegian: are they really? Evidence from EMA and EPG." *Processings of the 5th Seminar on Speech Production*, Zeon, Germany.

Skjærvø, Prods (1989a) "Modern East Iranian languages." In: Schmitt (ed.); 370-383.

Skjærvø, Prods (1989b) "Pashto." In: Schmitt (ed.); 384-410.

Skjærvø, Prods (1989c) "Yidgha and Munǰī." In: Schmitt (ed.); 410-410.

Smalley, William (1961) *Manual of Articulatory Phonetics*. South Passadena: Carey.

Spajić, Siniša, Peter Ladefoged & Peri Bhaskararao (1996) "The trills of Toda." *Journal of the International Phonetic Association* 26,1: 1-21.

Spencer, Andrew (1984) "Eliminating the feature [lateral]." *Journal of Linguistics* 20: 23-43.

Sridhar, S.N. (1990) *Kannada*. London: Routledge.

Steriade, Donca (1995) *Positional Neutralization*. Manuscript, University of California, Los Angeles.

Steriade, Donca (1997) *Phonetics in Phonology: the case of laryngeal neutralization.* Manuscript, University of California, Los Angeles.

Steriade, Donca (1999) "Licensing laryngeal features." *UCLA Working Papers in Phonology* 3: 25-146.

Steriade, Donca (2001a) "Directional Asymmetries in Place Assimilation." In: Hume & Johnson (eds.); 219-250.

Steriade, Donca (2001b) *The Phonology of Perceptability Effects: the P-map and its consequences for constraint organization.* Manuscript, University of California, Los Angeles.

Stevens, Kenneth (1996) "Articulatory-Acoustic-Auditory Relationship." In: W. Hardcastle & J. Laver (eds) *The Handbook of Phonetic Sciences*. Oxford: Blackwell; 462-506.

Stevens, Kenneth (1998) *Acoustic Phonetics*. Cambridge, Massachusetts: MIT Press.

Stevens, Kenneth & Sheila Blumstein (1975) "Quantal Aspects of Consonant Production and Perception: a Study of Retroflex Stop Consonants." *Journal of Phonetics* 3: 215-233.

Stevens, Kenneth & Sheila Blumstein (1981) "The search for invariant acoustic correlates of phonetic features." In: P.D. Eimas & J.L. Miller (eds.) *Perspectives on the Study of Speech*. Hillsdale, NJ: Erlbaum; 1-38.

Stevens, Kenneth & Samuel Jay Keyser (1989) "Primary features and their enhancement in consonants." *Language* 65: 81-106.

Stevens, Kenneth, Samuel Keyser & Haruko Kawasaki (1986) "Toward a phonetic and phonological theory of redundant features." In: J.S. Perkell & D.H. Klatt (eds.) *Invariance and Variability in Speech Processes*. Hillsdale: Erlbaum. 426-449.

Sundberg Johan & Björn Lindblom (1990) "Acoustic Estimations of the Front Cavity in Apical Stops." *Journal of the Acoustical Society of America* 88, 3: 1313-1317.

Sussman, Harvey M. & J. Shore (1996) "Locus equations as phonetic descriptors of consonantal place of articulation." *Perception & Psycholinguistics* 58: 936-946.

Sussman, Harvey M., Nicola Bessell, Eileen Dalston & Tivoli Majors (1997) "An investigation of stop place of articulaton as a function of syllable position: a locus equation perspective." *Journal of the Acoustical Society of America* 101, 5: 2826-2838.

Svantesson, Jan-Olof (2001) "Phonology of a southern Swedish idiolect." *Lund University Working Papers* 49: 156-159.

Švarný, O. & Kamil Zvelebil (1955) "Some remarks on the articulation of the 'cerebral' consonants in Indian languages, especially in Tamil." *Archiv Orientalni* 23: 374-434.

Tharp, George (1972) "The position of Tsetsaut among the Northern Athapaskans." *International Journal of American Linguistics* 38: 14-25.

Torp, Arne (2001) "Retroflex consonants and dorsal /r/: mutually excluding innovations? On the diffusion of dorsal /r/ in Scandinavian." In: H. v. d. Velde & R. v. Hout (eds.); 75-90.

Trask, Robert L. (1996) *A Dictionary of Phonetics and Phonology*. London: Routledge.

Trubetzkoy, Nikolai S. (1939) "Grundzüge der Phonologie." *Travaux du Cercle linguistique de Prague* 7, Prague: Prazský Lingvistický Krouzek.

Tuttle, Siri (1998) *Metrical and Tonal Structures in Tanana Athabaskan*. PhD dissertation, University of Washington.

Van der Velde, Hans & Roeland van Hout (eds.) *'r-atics: Sociolinguistic, phonetic and phonological characteristics of /r/*. Université Libre de Bruxelles: Etudes & Travaux, 1999.

Vanvik, Arne (1972) "A Phonetic-Phonemic Analysis of Standard Eastern Norwegian. Part I." *Norsk Tidsskrift for Sprogvidenskap* 26.2: 119-164.

Vanvik, Arne (1973) "A Phonetic-Phonemic Analysis of Standard Eastern Norwegian. Part II." *Norsk Tidsskrift for Sprogvidenskap* 27: 101-139.

Vennemann, Theo (1974) "Sanskrit 'Ruki' and the Concept of a Natural Class." *Linguistics* 130: 91-97.

Verstraeten, Bart & Hans Van de Velde (2001) "Socio-geographical variation of /r/ in Standard Dutch." In: H. v. d. Velde & R. v. Hout (eds.); 45-62.

Wängler, Hans H. (1958) *Atlas deutscher Sprachlaute*. Berlin: Akademie-Verlag.

Wakelin, M.F. (1972) *English dialects: An introduction*. London: Athlene Press.

Walley, A.C. & T.D. Carrell (1983) "Onset spectra and formant transitions in the adult's and child's perception of place." *Journal of the Acoustical Society of America* 73: 1011-1022.

Walsh Dickey, Laura (1997) *The phonology of Liquids*. PhD dissertation, University of Massachusetts at Amherst.

Warner, Natasha (1999) "Timing of perception of vocalic distinctive features: Implications for vowel system universals." *Proceedings of the 14th International Congress of Phonetic Sciences, San Francisco*, 1961-1964.

Wells, John C. (1982) *Accents of English*. 3 volumes. Oxford: Oxford University Press.

Whitney, William Dwight (1889) *Sanskrit Grammar*. Cambridge: Harvard University Press.

Wierzchowska, Bożena (1965) *Wymowa polska*. Warszawa: Państwowe Zakłady Wydawnictw Szkolnych.

Wierzchowska, Bożena (1980) *Fonetyka I Fonologia Jézyka Polskiego*. Wrocław: Zakład Narodowy imienia Ossolińskich.

Wiese, Richard (2001) "The unity and variation of (German) /r/." In: H. v. d. Velde & R. v. Hout (eds.); 11-26.

Wilkinson, Karina (1988) "Prosodic Structure and Lardil Phonology." *Linguistic Inquiry* 19,2: 325-334.

Williamson, Kay (1977) "Multivalued features for consonants." *Language* 53: 843-871.

Winitz, H., M.E. Scheib & J.A. Reeds (1972) "Identification of stops and vowels for the burst portion of /p, t, k/ isolated from conversational speech." *Journal of the Acoustical Society of America* 51: 1309-1317.

Wood, Sidney A.J. (1996) "Assimilation or coarticulation? Evidence from the temporal co-ordination of tongue gestures for the palatalization of Bulgarian alveolar stops." *Journal of Phonetics* 24: 139-164.

Yip, Moira (1996) "Lexicon Optimization in Languages without Alternations." In: Jacques Durand & Bernard Laks (eds.) *Current Trends in Phonology: Models and Methods*. Salford: ESRI; 354-385.

Zoll, Cheryl S. (1996) *Parsing below the segment in a constraint based framework.* Doctoral thesis, University of California at Berkely. ROA 143.

Zvelebil, Kamil (1970) *Comparative Dravidian Phonology*. The Hague: Mouton.

Index