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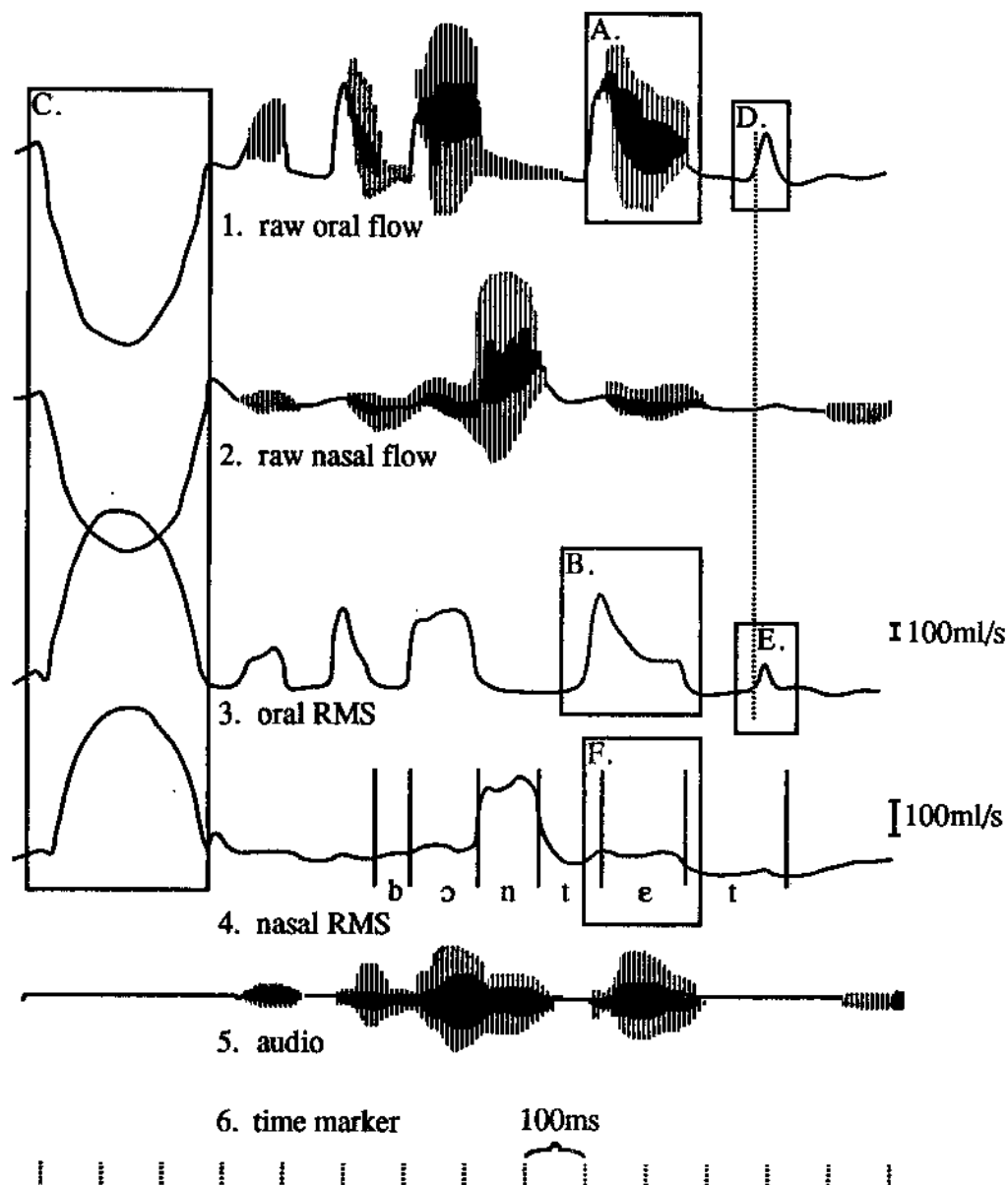
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Abigail C. Cohn



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Phonetic and Phonological Rules of Nasalization

by

Abigail C. Cohn

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Note: Tracings of the full corpus of filtered nasal flow data (all repetitions of the filtered nasal flow data for two speakers for each of the three languages) appear in appendices in the University of Michigan Microfilms version of the dissertation and are also available from the author (@ \$9.00 including xeroxing and mailing).

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A preliminary version of part of Chapter 3 appears as "Phonetic evidence for configuration constraints," in *Proceedings from NELS 19*. A discussion of some of the issues presented in Chapter 5 (§5.4 and §5.6.4) will appear as "The dual status of Anticipatory Nasalization in English," in *CLS 26*.

CHAPTER 1 INTRODUCTION

Phonetics and phonology are often defined as distinct areas of study. Phonetics is the study of the physical properties of sounds used in human speech: their production, their acoustics, and their perception. Phonology is the study of how speech sounds pattern together. Yet there is also an implicit derivational relationship between the two: a phonological representation indicates the linguistically important characteristics of sounds; the phonetic representation is the physical output or realization of that phonological representation, what the speaker actually produces or the hearer perceives. There is good evidence from psycholinguistics that abstract phonological representations exist for speakers and that this is part of what they "know" about their language. The nature of the relationship between abstract linguistic representations and the actual physical output is important for our understanding of language as a human cognitive process, offering us insight into one part of the linguistic behavior of both speakers and hearers in using human language. It is in this light that an understanding of the mapping processes from distinctive contrasts to physical events is a central issue in our general understanding of phonology. Following this view, we will take it that there is a systematic, albeit complex, mapping between the contrasts and the physical events. An investigation of this mapping and the presentation of computational principles to account for it are the central goals of this study.

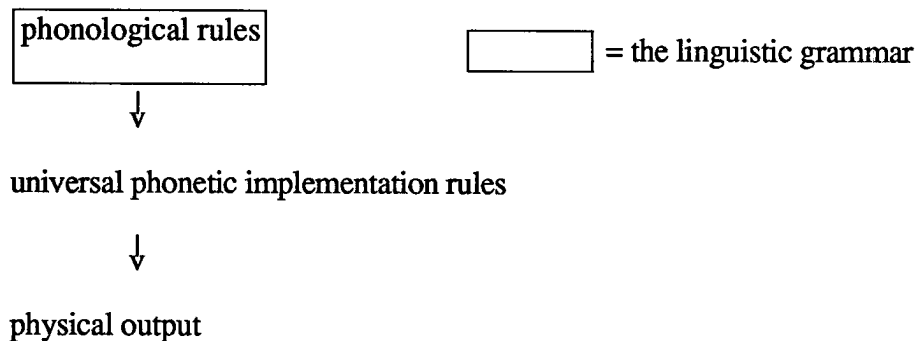
It is often assumed that mapping from an abstract representation, a representation viewed in categorial terms, to the physical output is a fairly mechanical process; the specifics of this process are usually only hinted at. This topic has recently begun to receive attention (notably Pierrehumbert 1980, Beckman and Pierrehumbert 1986, Pierrehumbert and Beckman 1988, and Keating 1984; 1985a; and 1988a). Their work shows that the mapping from the phonology to the phonetics is in no sense trivial. In this dissertation, I undertake a study of the mapping from an abstract phonological representation, viewed in terms of discrete and timeless segments, to a quantitative, phonetic representation, realized in time and space. This mapping is investigated through a detailed study of the feature Nasal, its phonological behavior and its phonetic implementation. Central questions addressed include the characterization of phonetic vs. phonological rules, formal properties of phonetic rules, and the nature of the phonetic representation for the feature Nasal. In this first chapter, some background and assumptions are laid out.

1.1. Development of the relationship between phonetics and phonology

In order to study the derivational relationship between phonology and phonetics, we must first address the issue of distinguishing between the two. Within the framework of generative phonology, phonological representations and derivations have been assumed to be a central part of the grammar, but until recently phonetics was often assumed to fall outside of the domain of the linguistic grammar. A widely accepted view, following Chomsky and Halle (1968, hereafter SPE), was that phonetic implementation was universal. This was discussed explicitly in terms of coarticulation. Coarticulation, the overlapping or blending of neighboring segments, was assumed to follow from general non-linguistic principles, such as the physiology of the vocal tract. Stated more generally, phonetic implementation or the physical realization of the abstract patterns represented by the phonology was assumed to be mechanical. As a consequence, a phonological output was assumed to have a unique physical realization. For example, in English, vowels are longer preceding a voiced stop than a voiceless one: the vowel in *bad* /bæd/ is longer than in *bat*

/bæt/. This was not taken as evidence of a phonological length difference in English, but, rather, was assumed to follow from mechanical implementation of the voicing contrast. It was also assumed that such differences occurred cross-linguistically. Under this view, the distinction between phonetics and phonology appeared clear-cut. Phonology involved language specific rules, whereas phonetics was the universal, mechanical realization of the phonology. This view is schematized in (1), where only the phonological rules were part of the linguistic grammar.

(1) Traditional view (SPE)

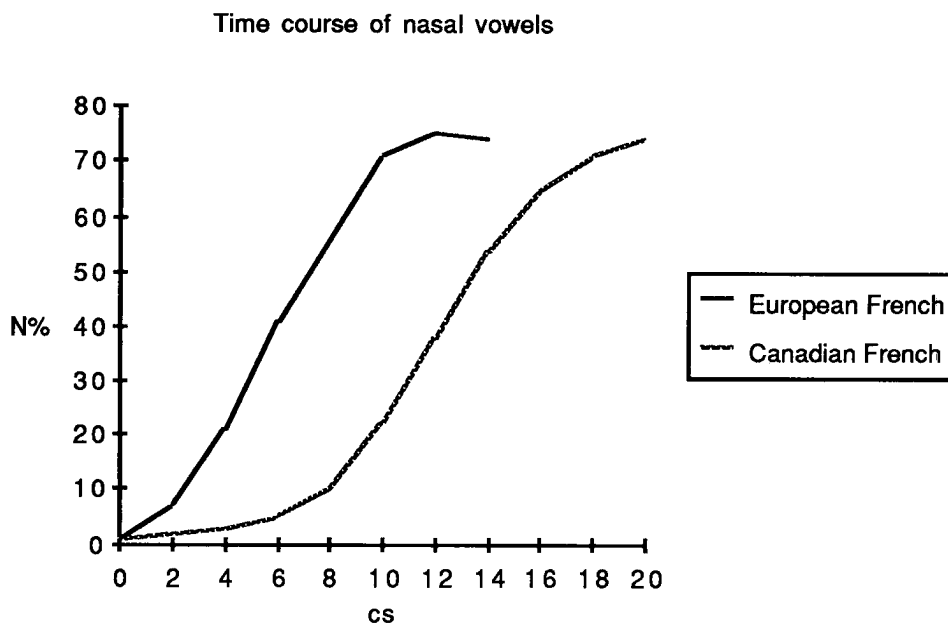


Since the phonetics was "automatic", there was no notion of there being a phonetic rule system as such. As the mapping was thought to be universal, little attention was paid to the phonetic implementation of phonological representations from a linguistic point of view. Such questions were the purview of phonetics alone and not thought to be of interest to the phonologist.

More recently, this view has changed. Extensive evidence has been provided for the language specific nature of phonetics. Many phonetic processes that were assumed to be mechanical and to follow from physiological factors, on closer inspection, turn out to show significant differences between languages. In such cases, a purely physiological explanation is no longer tenable. One such example, quite widely discussed in the literature, is the observation about vowel length mentioned above (see Chen 1970, Fromkin 1976, Anderson 1981 and Keating 1985b, among others). Physiological explanations have been offered, but these do not account for the observed cross-language differences. Another such example is velum movement. For example, in English, it has been argued that contextual nasalization of vowels is due to the "sluggishness" of the velum. But studies have shown that the velum can move much more quickly than the degree of coarticulation observed in English would suggest. Furthermore, cross-linguistic work has shown significant language differences with respect to the timing of contextual nasalization (Clumeck 1976). At best, we can say that these effects are physiologically motivated tendencies (see Anderson 1981).

Phonetic differences can even occur between closely related dialects. Such is the case with the realization of the time course of nasal vowels in European French and Canadian French, as shown in (2):

(2)



Time course of nasal vowels of European French & Canadian French

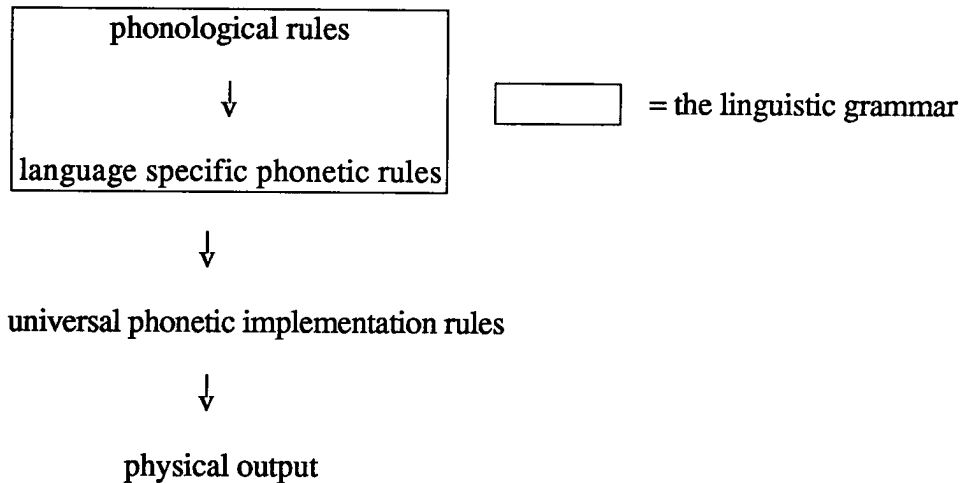
After van Reenen (1982) p. 74, showing a graphic representation of averages of 12 European French and 31 Canadian French nasal vowels in nonnasal environments, based on measurements from tracings in Charbonneau (1971) and Brichler-Labaeye (1970). Time in cs on the x-axis and the value for N% on the y-axis,

$$N\% = \frac{\text{nose coupling}}{\text{mouth coupling} + \text{nose coupling}} \times 100$$
, where N = Nose Coupling, the opening in mm² of the nasal port in a cross-section perpendicular to the airstream at the point of greatest constriction between the velum and the pharyngeal wall.

In (2) we see the time course of velum movement during a nasal vowel in European French compared with Canadian French (e.g. [ɔ̃] as in *bon* [bɔ̃] 'good' (m.)). This figure (adapted from van Reenen 1982) shows averages of nasal opening vs. time for nasal vowels in non-nasal environments, measured from x-ray tracings for European French and Canadian French from Brichler-Labaeye (1970) and Charbonneau (1971) respectively. We see that there is a different time course, with the onset of velum lowering (onset of nasalization) occurring much sooner in European French than Canadian French. The difference is not a mechanical one; there is no reason to assume that the physiology of Canadian speakers of French is different from that of European speakers. Yet it cannot be accounted for in an obvious way by differences in the phonological system, since the value of nasal vowels in the two systems is the same (at least superficially). Finally, these language specific differences are systematic ones, and thus appear to be rule governed.

Based on such evidence, it has been convincingly argued that at least some portion of phonetic rules is indeed part of the linguistic grammar and is not to be relegated to the "universal phonetic" component, leading to a view such as the one schematized in (3), where both the phonological and the language specific phonetic rules are part of the grammar.

(3) Current view



This more complex view leads to certain empirical questions about both rules and representations. Since it is now accepted that there is a class of language specific phonetic rules, which are therefore part of the linguistic grammar, the characterization of these as a class in contrast to phonological rules becomes a substantive issue.

One possible view of the relationship is that language specific phonetic rules are a subset of phonological ones and should be accounted for with phonological rule mechanisms and representations. Another view is that phonological rules and language specific phonetic rules differ crucially in that what they manipulate is different: phonological rules manipulate discrete categorial representations, whereas phonetic ones manipulate quantitative ones. This fundamental difference necessitates that different formal mechanisms are involved. It is this latter position that will be taken here. We therefore should seek a principled characterization of the difference between phonological and phonetic rules which follows from these different properties.

In order to discuss the relationship between phonetics and phonology, we first need to sketch out an explicit view of phonology and phonetics respectively (the latter is, of course, to some degree dependent on assumptions involving the former.) The structure of this chapter will be as follows. In §1.2 and §1.3, we discuss phonological rules and representations and phonetic rules and representations respectively. In §1.4, we consider the characterization of phonological rules vs. phonetic rules. In §1.5, we discuss the feature Nasal. In §1.6, we consider the role of variability in phonetics and phonology as well as a few other terminological issues. A brief overview of the study is given in §1.7.

1.2. Phonological background and assumptions

Although there is strong evidence that segments are a psychologically relevant level of representation, it is also clear that segments consist of smaller units or features. In more recent work, it has also been argued that particular features may function independently (as separate tiers) (Goldsmith 1976, Clements 1976) and that there is some kind of logical hierarchical structure among features, that is, an internal structure to the segment (Clements 1985, Sagey 1986). A

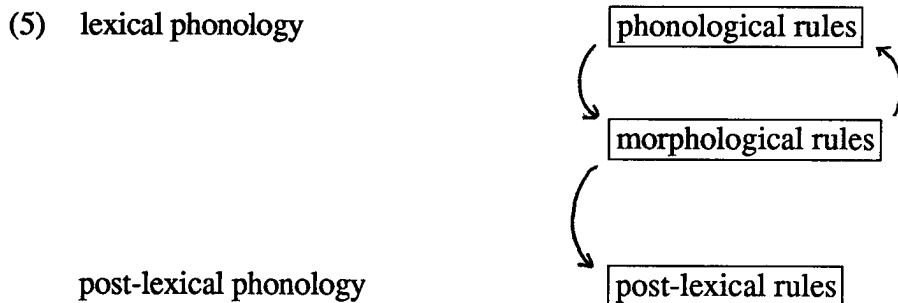
well-formed underlying phonological representation involves feature specifications assumed to bear a universally determined relationship to one another. Rules of the phonology can manipulate this representation in various ways. Under this view, assimilation, an extremely common type of rule cross-linguistically, consists of feature spreading in a local fashion; the result of such rules is linked structures of various sorts. Rules may result in the delinking of features as well. In effect, these phonological rules add and delete association lines. Well-formed phonological structure includes both a segmental representation and a prosodic one (that is, syllabic structure, metrical structure and so forth).

1.2.1. Phonological rules

There has been much discussion in the phonological literature about patterns of phonological rule behavior and how they interact. The following clustering of properties has been observed, as summarized in (4).

- | | | |
|-----|---|--|
| (4) | <u>cyclic</u>
derived environments
exceptions | <u>non-cyclic</u>
across-the-board
no exceptions |
|-----|---|--|

It has been observed that typically cyclic rules apply only in derived environments (unless they are structure building) and allow exceptions. On the other hand, non-cyclic rules typically apply across-the-board and in an exceptionless fashion. If one takes the position that a subset of the phonological rules are interleaved with the morphology, the above observations follow directly. This is the position taken by Kiparsky (1982, 1983) and Mohanan (1982), within the framework of Lexical Phonology. The rules that interact with the morphology are said to be "lexical" rules and have the chance to reapply after each morphological operation. These rules are inherently cyclic. Rules which apply in an across-the-board fashion, those which are not affected by morphological structure, are called "post-lexical" rules and are argued to apply at the end of the grammar, after all of the lexical rules. This division gives a view of the grammar such as the one schematized in (5).



The lexical rules correspond with what has been called the "deep phonology". The post-lexical rules are nearer the surface and include the class of allophonic rules. Mohanan (1982) argues that the end of the lexical phonology has a special status. One aspect of this is the claim that speakers appear to judge sameness and distinctiveness at this level, not at the underlying level or a more surface level. The phonological inventory may be distinct from the underlying inventory; the

former is termed the "lexical alphabet". Speakers' awareness of a rule's effect may be taken as support for something being part of the lexical phonology. In contrast, naive native speakers are assumed to be insensitive to allophonic variation in their language; e.g. speakers of English typically judge the /p/ of *pit* [p^hɪt] and the /p/ of *spit* [spɪt] as being the same. These distinctions will be important below, in §1.4, where we will try to distinguish between different rule types.

1.2.2. Phonological representations

It is worth considering in some detail the nature of phonological representation, in both time and space. Within the phonology, representations are categorical, generally assumed to be binary. As stated above, I assume that the phonological representation is in terms of segments, consisting of a hierarchically structured set of distinctive features. The segment also includes an abstract duration, currently represented independently from the feature matrix itself. The space dimension is represented as a feature value: positively specified (+), negatively specified (-), or unspecified (∅). (The issue of unspecified values will be taken up below.) Thus, possible representations for the feature Nasal include only [+nasal], [-nasal], and [∅nasal] as exemplified in the English word *can* /kæn/, shown in (6).

(6)

k	æ	n
[-nasal]	[∅nasal]	[+nasal]

The possible timing contrasts available within the phonology are very limited. The inherent durations of different segment types do not play a role in the phonology. Only a very gross characterization of timing appears to be relevant. The relevant categories within a segment appear to be two units, one unit, and "part" of a unit (unspecified for specific duration or proportion). More complex structures may arise through phonological derivation, e.g. Inouye's (1989) analysis of flaps in English as well as her reanalysis of medio-nasals in Kaingang (as discussed by Anderson 1976), both of which are argued to involve structures with three branches. But there is little evidence for structures with more than two branches in underlying representation, with the possible exception of underlying flaps, also discussed by Inouye.

These categories are captured within current phonological theory as timing units (either C's and V's (e.g. Clements and Keyser 1983) or x's (e.g. Levin 1985), or as weight units (e.g. Hyman 1985)). An x or a C or V slot is one timing unit. The mapping between segment quality, that is the features, and timing units represents abstract timing relationships, as exemplified in (7) (using x's).

(7)

a. x	b. x x	c. x
	\ /	/ \
α	α	α β

The representation in (7a) is that of most segments, one set of features for one timing unit. That of (7b) represents one set of features taking up two timing units, such as a geminate consonant or a long vowel. That of (7c) represents a contour segment, such as an affricate, a prenasalized stop, or a short diphthong. These can be viewed as two feature matrices attached to one timing unit, or in a more constrained interpretation, a feature matrix in which only one feature

branches (Sagey 1986). It has been observed that, although geminates are consistently longer in duration than single segments, the relative timing of single segments and long segments varies from language to language. This does not invalidate the notion of timing units, but rather shows that they are abstract entities. On an abstract level only, geminates are twice as long. But the actual physical timing is a matter of phonetic realization which is, to some degree, language specific.

The representation in (7c) implies that two feature specifications share one timing unit. Each specification gets part of the whole. It does not say what the specific timing relationships are. This again would be language specific. It has been shown by Chan and Ren (1987) that prenasalized stops vary in their relative timing, yet I assume that this would not affect the phonological representations. A prediction that follows from this is that no language will distinguish between single unit contour segments of different proportions (e.g. [m^b] vs. [m^b], where superscript denotes shorter duration). To my knowledge, no language makes a phonological contrast of this sort.

In sum, within the phonology, feature specifications are represented as only +, -, and Ø; timing is represented in abstract units: x, two x's, or part of x. At the end of a phonological derivation, the output is in some sense still a static one, with logical structure, relative ordering relationships between segments (or feature specifications), but no actual (concrete) durations, or actual quantities along the physical dimensions corresponding to features. Rather it is the job of the phonetics to assign real durations and actual quantities. How this is done, of course, affects the nature and status of the phonetic representation.

1.2.3. Degree of feature specification

An area of interest in the recent phonological literature has been the degree of specification in phonological representations. In other words, is it the case that for every segment each feature is specified for a + or - value? If so, the representation is a fully specified one. If not, if Ø is a possible value, there is said to be "underspecification". In SPE, even though lexical representations were underspecified, with values provided through markedness and predictability of certain feature values from other feature specifications, it was explicitly stated that all features must be fully specified in the phonology. Thus all values were filled in at the level of underlying representation of the phonology. This led to a constrained view of feature representation, but a rather un insightful view of certain phonological processes, such as harmony rules, which were represented as feature changing rules. Recently this constraint on full specification has been rejected (Kiparsky 1982, Pulleyblank 1983, and Archangeli 1984); it is now generally assumed that some degree of underspecification is used by the phonology. Yet there is much debate in the literature as to the degree of underspecification allowed, the way that underspecification should be constrained or restricted, and how rules interact with representations which are not fully specified (cf. Kiparsky 1985, Archangeli & Pulleyblank 1986, Steriade 1987a, Clements 1987, Christdas 1988, Archangeli 1988, and Mester and Itô 1989, for discussion of these issues.)

Two types of approaches to underspecification have played a central role in the discussion: (a) the approach taken by Kiparsky (1985) and Archangeli and Pulleyblank (1986), often referred to as "Radical Underspecification", in which no reference is made underlyingly to either redundant or unmarked values; following this view, the unmarked value of a feature cannot be referred to underlyingly or in the phonology, until filled in by rule; (b) the type of approach taken by Steriade

(1987a) and Clements (1987), referred to by various names in the literature, referred to here as "Contrastive Underspecification", where in case of contrast, both feature values may be referred to in the underlying representation, but in the case of redundant specification, no value is referred to. See Archangeli (1988) and Mester and Itô (1989) for insightful discussion of the development of underspecification theory and comparison of these two types of theories. What is relevant to the present discussion is that, under both of these approaches, there is no specification of feature values that do not contrast. I will refer to any such view as an underspecification approach. Throughout this study, I will assume that there is some degree of underspecification and that certain phonological patterns may be due, not to individual feature specification, but to more general principles. It will be seen that phonetic data can play a crucial role in determining the degree of phonological specification.

1.3. Phonetic rules and representations

1.3.1. Phonetic representations

In SPE, it is assumed that there is a phonetic level of feature representation, the "phonetic transcription", at which point binary values are translated into a small number of discrete categories. The phonetic transcription is described as follows:

The phonetic transcription can therefore be taken to be a two-dimensional matrix in which the columns stand for consecutive units and the rows stand for different features. At this level of representation each feature is to be thought of as a scale. A particular entry in the matrix, then, indicates the position of the unit in question on the given scale. The total set of features is identical with the set of phonetic properties that can in principle be controlled in speech; they represent the phonetic capabilities of man and, we would assume, are therefore the same for all languages. (pp. 294-5.)

This, then, is a linguistically relevant, discrete, phonetic representation. Everything beyond the phonetic transcription is assumed to be universal. Anderson (1974) offers a concrete instantiation of such a phonetic representation. As an example, he discusses three possible phonetic values for the feature Nasal in the Breton dialect of Plougrescant – [Onasal], [.3nasal] and [.7nasal] – on a scale of zero to one, to describe oral vowels in an oral context, oral vowels next to a nasal, and distinctively nasal vowels respectively. Such an approach, in effect, codifies the phonetic values that exist at the level of the phonetic representation (which Anderson notes are only significant in their relative relationship to each other).

This SPE-type view gives a formal status to the phonetic representation – a still discrete, but detailed, representation. It is not obvious that such a level of representation is necessarily warranted. It might also be the case that the status of the phonetic representation is different for different features. The first question to consider is whether there are identifiably relevant degrees along the scale for a particular feature. Put another way, we can ask whether there are a certain number of points along the scale that are linguistically relevant. This is an empirical question. Keating (1984) argues that, for the feature Voice, there is evidence of an intermediate formal level of phonetic representation in terms of categories distinct from the phonological categories. She offers a detailed and formal proposal for such a level of representation for Voice. She argues that the phonological feature Voice is represented at an intermediate stage as three phonetic categories:

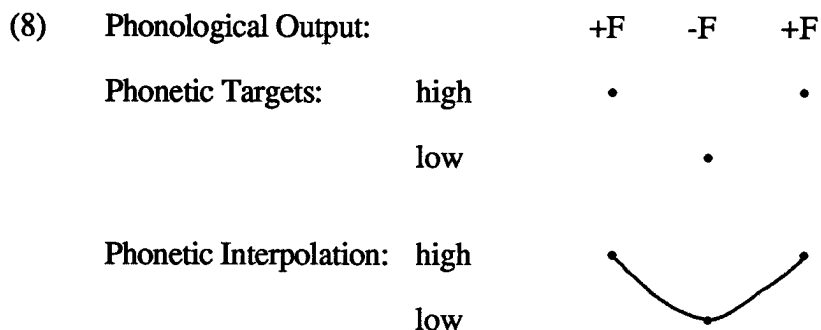
[voiced], [voiceless unaspirated], [voiceless aspirated]. Different languages will map the two binary values [\pm voice] differently into the phonetic mapping. This accounts for the kind of similar phonological processes observed across languages with respect to Voice, even though what is "voiced" in one language may count as "voiceless" in another. But from this evidence alone, it does not follow that such a level of representation necessarily exists for other features. Pierrehumbert's (1980) analysis of intonation in English gives no formal status to the phonetic representation as such. In this case, phonetic representation(s) is(/are) created as the rules of implementation act on the phonological representation. As will be shown in this study, the feature Nasal is more like intonation in this respect, not providing evidence of an intermediate formal representation.

Much of the discussion of the relationship between phonology and phonetics has focused on the nature of the phonetic representation (Chomsky and Halle 1968, Ladefoged 1977, Anderson 1974, Mohanan 1986, van Reenen 1982). This emphasis on representation rather than process results, I believe, from the formal status attributed to the phonetic transcription as defined by Chomsky and Halle (as discussed above). But such a level of phonetic representation may or may not be relevant to implementation. Following the view of implementation proposed by Pierrehumbert (1980) and Pierrehumbert and Beckman (1988), the phonetic representation is an extension of the phonological representation. The phonologically discrete units get increasingly blurred through the implementation of different parameters. What is taken as the phonetic representation is a result of the phonetic implementation; it may or may not be the case that such representations should be formally codified. Thus for example, the [.3nasal] level observed on vowels next to a nasal consonant in Breton might arise from the transition between an oral segment and a nasal segment. The [.3nasal], although descriptively accurate, may not be directly relevant to our understanding of the mapping. It might be the case that such a value is the result not of a phonetic target, but of a transition between two more extreme values. Values such as [.3nasal] may arise as a result of change over time. If this is the case, we can still describe the phonetic event in these terms, but do not necessarily want to ascribe a formal status to this description. In the analysis in this study, although phonetic representations are presented, we focus primarily on the process of implementation, in the belief that the phonetic representation of the feature Nasal follows from its implementation.

1.3.2. Phonetic implementation

The formal properties of phonological rules have been a topic of ongoing research in generative phonology; the formal properties of phonetic implementation rules are much less studied and much less clearly understood. An outstanding exception to this is Pierrehumbert's (1980) dissertation, in which she proposes a model of intonation in English which explicitly goes from an abstract (sparse) phonological representation to actual physical output. This approach has been developed in further work (notably Beckman and Pierrehumbert 1986 and Pierrehumbert and Beckman 1988). Such analysis relies heavily on phonetic implementation rules. Pierrehumbert develops the traditional distinction in implementation between evaluation and interpolation rules. The former rules evaluate feature values, translating them into phonetic targets; targets are located in both time and space. The latter rules connect up targets. This approach offers a possible model for examining segmental processes; such a model has been proposed by Keating (1988c).

Following this type of approach, feature values leaving the phonology are translated into phonetic targets, such that a plus value translates to relatively more of the physical value that implements a particular feature than a minus value. These targets are then hooked up through interpolation. This model of phonetic implementation, the "target-interpolation" model, is exemplified in (8):



In this example, we see a sequence of segments with values for some feature F. The vertical scale is the physical dimension. The target evaluation rules assign phonetic targets based on phonological specification, with the +F specifications receiving a high target, and -F a low target, for the particular phonetic parameter (or parameters) that corresponds to the phonological feature. I assume for the moment that targets consist of single points located in the middle of the duration of a segment. I assume also that there is a smooth interpolation between the targets.

This model raises issues about the nature of both target assignment and interpolation. Little is known about the formal properties of interpolation. Certain cases appear to follow from the connection of two targets with a straight line. This is the case for some of the intonational patterns described by Pierrehumbert or the case of jaw lowering (see Keating 1987). But consideration of a broader range of data makes it clear that a restrictive theory of interpolation which allows only for straight lines is not empirically adequate. Some of the patterns presented by Pierrehumbert as well as the case of tongue backing in Arabic discussed by Keating (1987) show greater complexity. Pierrehumbert (1980) proposes a theory of interpolation, including three types of curves to account for the patterns that she presents. This is an important area for further research, as the range of possible interpolation curves has yet to be constrained.

There are other models of implementation that one might appeal to, as well as certain modifications of the above model that one might make. One such model is the "look ahead" model of Henke (see Keating 1988b for a discussion of this model and its history). In this model a feature value changes as soon as it is able to. One can think of this as on-off switches, with the principle being to change to the next value as soon as possible. As has been argued elsewhere in the literature, such a model is not adequate to account for the facts of nasalization (cf. Kent, Carney and Severeid 1974 and Benguerel, Hirose, Sawashima, and Ushijima 1977a, among others).

Other possible models emerge from rule-based systems of segmental speech synthesis (e.g. Holmes, Mattingly, and Shearme 1964; Mermelstein 1973; Allen, Hunnicutt, and Klatt 1987; among others). These include a variety of rule types and other formal mechanisms, some of which will play a role in the subsequent analysis and discussion.

In the present study, a target-interpolation model will be taken as the starting point. It will be argued that such a model needs to be modified and extended to account for the observed facts. With respect to targets, it will be argued that they need to be modified in terms of both time and space (in both the vertical and horizontal dimensions). One provocative modification to a target-interpolation model, along the vertical dimension, is Keating's (1988a) Window Model. Keating proposes an explicit model of interpolation and phonetic spreading which assumes that rather than having a single target for each specified value, there are ranges within which interpolation must stay. Thus a segment with a very narrow window would appear to be one with a specific target and one with a wide window would appear to be underspecified. This approach offers an account for certain kinds of variability, as well as constraining possible types of interpolation. We will see below that windows, or ranges of values, appear to play a role in implementation of the feature Nasal. The nature of targets along the time dimension will be considered below. It will be argued that targets have inherent duration and a specific account of such duration will be proposed.

1.3.3. Phonetic underspecification

An issue basic to the discussion of phonetic implementation is whether there is necessarily full specification of features leaving the phonology. Full specification leaving the phonology is of course assumed in any theory which does not allow underspecification. But even under certain views of phonological underspecification, it is often assumed that there is full specification at the end of the phonological derivation, due to default fill-in rules (e.g. Archangeli and Pulleyblank 1986). In contrast, in order to account for patterns of pitch, as measured from F0 traces, Pierrehumbert (1980) assumes a sparse phonological output. Not every syllable which is potentially the bearer of a pitch accent receives such an accent. In effect then, the phonological output is not fully specified along the dimension that is implemented as intonation. Another such example is the realization of the vowel-like quality of intervocalic [h]. Keating (1988b) has argued that the traditional view of vowel quality of [h], whereby it is assumed that [h] gets its vowel-like qualities from the following vowel by a phonological rule of assimilation, is empirically inadequate. As discussed below, in order to account for her observations, it is necessary to abandon the assumption that there is full specification leaving the phonology.

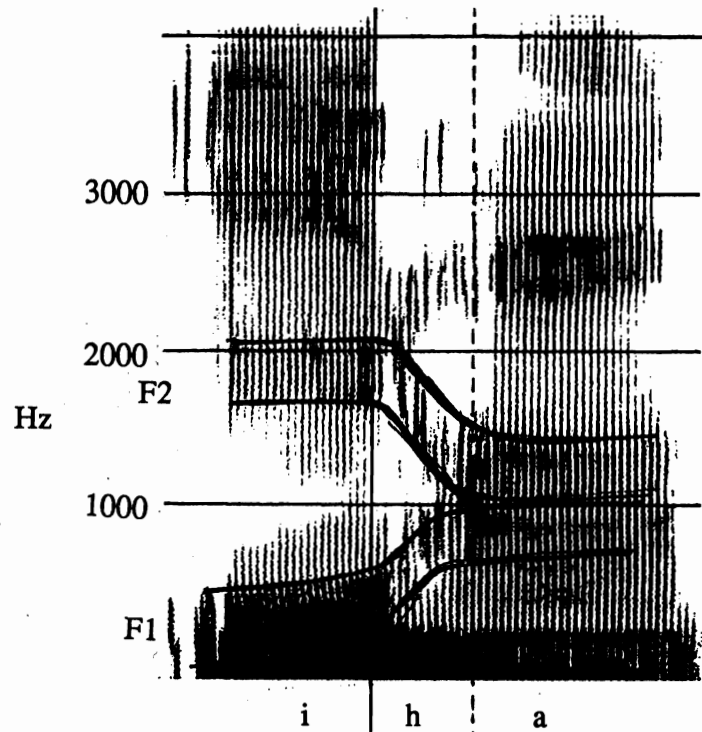
The target-interpolation model taken together with the possibility that there is not full feature specification leaving the phonology leads to the following schematic view of implementation: a plus value of a feature should translate to a relatively high level; a minus value to a low level, and an unspecified value would be expected to be determined by phonetic context. The rules of the phonetics evaluate the targets and connect them through interpolation. Three examples are given in (9):

(9)	a.	b.	c.
Phonological Output:	+F -F -F	+F ØF -F	+F ØF +F
Phonetic Targets:	high • low • •	high • low •	high • •
Phonetic Interpolation:			

In (9a) the form is fully specified for the feature F leaving the phonology. Targets are assigned, along some scale for the particular feature. These targets are then hooked up through interpolation, showing a fairly rapid transition between the neighboring high and low targets. In (9b), the first segment is [+F], the second segment is unspecified leaving the phonology and the final segment is [-F]. Only the first and last segments receive phonetic targets. There is interpolation between the targets and the middle segment receives a transitional amount of the scale for the feature F from the phonetic context. In (9c), both the first and last segments are specified as [+F] and the middle segment is again unspecified. Targets are assigned and in this case, there is interpolation straight through the middle segment. The unspecified segment receives a large amount of the scale for the feature F through phonetic context, giving the (erroneous) impression that it had a relatively high target, when in fact it has no target of its own.

Let us look at the vowel-like qualities of intervocalic [h], as discussed by Keating (1988b), as an example. It has commonly been assumed that [h] gets its vowel-like qualities from a phonological assimilation rule, where [h] assimilates to the vowel features of the following vowel. Were this the case, we would expect that [h] would have similar formant structure (the characteristic acoustic pattern of a vowel or vowel-like segment, indirectly related to the phonological vowel quality features) throughout most of its duration to that of the following vowel. Keating observed some formant patterns of [h] and concluded that the formant structure was not due to a phonological rule, but rather due to phonetic context. Consider relevant spectrographic examples, [iha] and [aha] presented in (10) and (11) respectively:

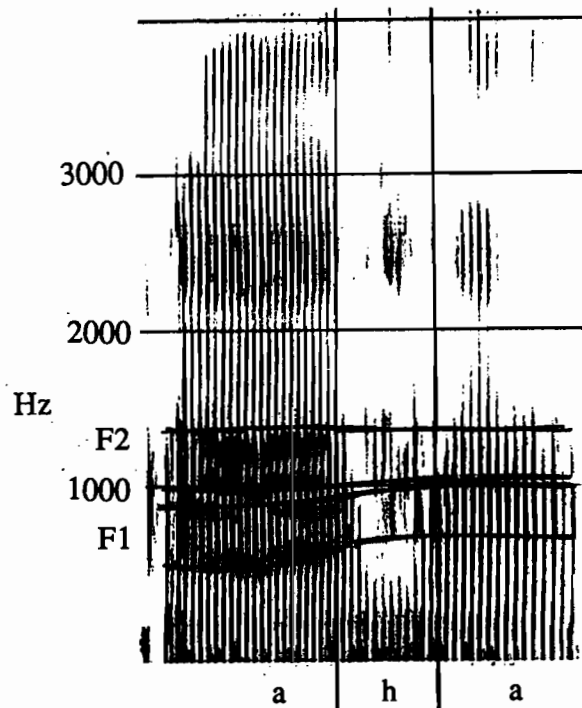
(10) [iha]



As shown in (10), [i] is characterized by having a low F1 (centered here at about 300 Hz) and a high F2 (centered just below 2000 Hz); [a] is characterized by a high F1 (centered at about 800 Hz) and a low F2 (centered at about 1200 Hz). The formant structure is constant throughout the duration of the vowel. Were it the case that [h] gets its formant structure from a phonological rule of assimilation from the following vowel, we would expect for the [h] to have formant values like the following [a] for most of its duration. This is not the case; rather, the F1 and F2 values are transitional throughout the full duration of the [h]. This can be explained in a straightforward fashion, if it is assumed that [h] is unspecified for vowel quality leaving the phonology; it therefore gets no phonetic targets of its own and its vowel-like qualities are from the phonetic context, due to interpolation.

Note that this conclusion is somewhat dependent on the segmentation of the [h] and the adjacent vowels. It is difficult to determine precise segmentation of this sequence, since the [h] is voiced throughout. I assume that the plateau-like portion at the transition between the [h] and following [a] is part of the [a] and not due to [h] having targets for F1 and F2 only at the end of its duration. Note also that [h] appears to have its own target for F3. We observe that the F3 is significantly lower at the onset of the [h] than it is at the end of the preceding vowel. This does not necessarily mean that [h] is specified for vowel features leaving the phonology, but rather that things are somewhat more complex and that the phonetics may impose constraints of its own. The realization of F1 and F2 for [h], then, looks very much like the pattern of phonetic implementation schematized above in (9b). Consider now the spectrogram in (11):

(11) [aha]



Here again the [a]'s both preceding and following the [h] are characterized by high F1's and low F2's. The formant structure of [h] is also characterized by a high F1 and low F2. Had we not considered the evidence from (10), we might (erroneously) assume that [h] has its own targets, high F1 and low F2, but based on the evidence in (10), it would be much simpler to assume that here too [h] has no vowel feature specifications of its own, therefore no phonetic targets, and that it too gets its vowel-like quality from the phonetic context, from interpolation between the neighboring targets. This then is like the pattern of phonetic implementation schematized in (9c). It is important to note that such cases could easily be misinterpreted as all three segments (that is, including the intermediate segment) having the same value specified. Comparison with forms where a transition might be expected throughout are crucial for determining such cases of underspecification leaving the phonology.

Keating's account of intervocalic [h] offers strong support for the view that there is not necessarily full feature specification leaving the phonology. The facts are amenable to an analysis in terms of the target-interpolation model (but could clearly be accounted for with other models of phonetic implementation as well). The assumption that there is not full specification leaving the phonology has important implications. (1) It is not necessarily the case there there are rules which assign phonological feature default values at the end of the phonology. (2) Since a well-formed phonological output may not be fully specified along all dimensions, it is an empirical issue to determine whether a particular representation is fully specified and whether or not default phonological values have been assigned.

To conclude this section, we adopt a target-interpolation model as a starting point to account for the phonetic implementation of the feature Nasal. A central assumption is the idea of phonetic underspecification, that there may be spans greater than the size of a segment without targets of

their own. It will be argued that such a model needs to be extended in terms of both time and space dimensions and that phonetic constraints must be incorporated.

1.4. Phonetic vs. phonological rules

With this brief sketch of rules and representations, both within the phonetics and phonology, we can now return to the question posed at the end of §1.1, that is, how we can distinguish between language specific phonetic rules and phonological rules.

The conclusion that there is indeed a class of language specific phonetic rules leads us to seek a principled way of characterizing such rules and distinguishing them from phonological rules. As we saw above, language specific differences in phonetic realization identify aspects of the phonetics which are not universal and therefore not mechanical. Such differences may serve as a device for identifying linguistically relevant phonetics. On the other hand, if it is claimed that such rules are distinct from the phonology, we need a systematic way of making this distinction.

One approach for distinguishing between phonological and phonetic rules was proposed by Liberman and Pierrehumbert (1984). Following the model of Lexical Phonology (Kiparsky 1982), they suggest that, except for phrasal rules, post-lexical rules are phonetic implementation rules. As discussed by Kiparsky (1985), this is too strong a position. There are post-lexical rules which Kiparsky argues are truly phonological in that they are feature changing. Kiparsky concludes that the post-lexical rules which involve gradience are in some cases probably phonetic implementation rules, but he proposes no specific mechanisms of phonetic implementation. His conclusion that some post-lexical rules are phonological in nature, applying categorially, whereas some are perhaps phonetic implementation rules, applying gradiently, is not in itself a solution. What are the formal properties of phonological rules on the one hand and phonetic ones on the other?

Let us consider the issue with respect to assimilation rules. Looking at the implications of Pierrehumbert's work for segmental features, Keating (1987, 1988a) observes the following about the difference between phonological and phonetic assimilation rules: Phonological rules manipulate discrete and timeless segments, whereas phonetic rules manipulate variables which are continuous in time and space; these differences are expected to be reflected in the outputs of these rules. As a consequence, phonological assimilation should result in static effects, where each segment has the attribute being shared. Phonetic assimilation should result in effects which are variable in time or space: only part of the segment might be affected; varying amounts of the attribute might be shared; or a segment might vary in quality continuously. This is an oversimplification of Keating's discussion, but serves our purposes for the moment. The clustering of these properties is summarized in (12).

(12) Keating's (1987, 1988a) characterization of assimilation rules:

<u>Phonological rules</u>	<u>Phonetic rules</u>
categorical	gradient/quantitative
discrete & timeless segments	continuous in time and space
static effects	segment may vary in quality continuously
full segment affected	part of a segment affected

By static, we mean output that does not change noticeably during the duration of time that we assume is associated with a particular segment or sequence of segments; such effects might be characterized as a plateau (along the space dimension). Gradient effects might be of different sorts; of particular interest to us here are cases of change in space over time, resulting in a cline-like effect. That static, categorial outputs are the result of phonology and gradient outputs from transitions between segments are the result of phonetics is not surprising. More interesting is the fact that phonetic rules may affect a full segment or more in a continuously varying way. This result follows directly from certain assumptions about the nature of phonetic implementation, most importantly the observation that there is not necessarily full specification of features leaving the phonology. The distinction is not always an obvious one. Phonetic output may at times appear to be categorial. Recall our discussion of the vowel-like qualities of [h], where we saw cline-like effects throughout the [h] when the preceding and following vowel were different, but static effects when the adjacent vowels were the same. We also cannot exclude the possibility that a phonological distinction may appear gradient; as when, for example, a target has only a brief point-like duration. Such a clustering of properties can be, at best, taken as guidelines.

With this general approach in mind, we can look at particular rules and judge whether they appear to be phonetic or phonological in nature. Ideally we will find independent support for our characterization. First, following the view of lexical phonology (Kiparsky 1982, 1983), rules which apply cyclically are lexical phonological rules, part of the deep phonology. If a rule applies cyclically, this can be taken as independent evidence that the rule is a phonological one, not a phonetic one. Second, if a rule applies within a certain domain, this also supports the view that it is phonological. Third, following Mohanan (1982), a criterion of speaker awareness might be applied.

A genuine counterexample to this clustering of properties would be a case where there is a rule, argued to be phonological, due to cyclic application or rule ordering, which is shown to apply in a gradient fashion or where an underlying contrast is realized gradiently (which can only be judged with phonetic data, since human ears tend to impose categorial impressions on gradient phenomena). One such possible exception is the case of realization of Hausa tone (Inkelas, Leben and Cobler 1987) where each syllable must be specified for a tone and a sequence of high tones appears to result in a gradient output.

Of particular interest are cases which appear to involve gradience in the phonology or where other aspects of what has been described as phonological rule application look phonetic. The hope is that such gradient cases will be amenable to reanalysis in terms of phonetic implementation.

Keating (1987 and 1988a) discusses several cases of gradient rule application that she argues are phonetic and not, as previously assumed, phonological. As discussed in §1.3.3, Keating has argued perspicuously that the vowel-like qualities of [h] are a result of phonetic implementation and not phonological assimilation. She has also argued that some vowel allophony in Russian and the spreading of emphasis from the emphatic consonants of Arabic are cases where a phonetic rule was misanalyzed as being phonological, i.e. categorial. Beckman and Pierrehumbert (1986) and Pierrehumbert and Beckman (1988) have argued that some aspects of pitch accent in Japanese are also a case of phonetic implementation, not phonological tone spreading. Each of these cases involves gradient behavior.

There are several interesting cases, discussed by Kiparsky (1985), in which gradience is involved. He discusses cases where the same rule seems to apply at different points in the grammar, once categorially, once gradiently. He argues that this is a result of lexical and post-lexical application of the same rule. I believe that these cases may be amenable to analysis in terms of phonetic interpolation through an unspecified span.

Two of the cases discussed by Kiparsky involve voicing, Sonorant Devoicing in English clusters and Russian Sonorant Voicing. In both cases, the realization of voicing of the sonorants can be very different from that of the obstruents: the voicing of sonorants may involve gradient effects, whereas the voicing of obstruents does not. Since Kiparsky assumes the principle of Structure Preservation, any rule of sonorant devoicing in languages such as English and Russian must be a post-lexical rule, whether its output is gradient or categorial; as obstruents, but not sonorants, contrast for voicing.

Let us pursue the case of English Sonorant Devoicing for a moment. As discussed by Kiparsky, a rule of Lexical Voicing Assimilation involves only obstruents, both as triggers and undergoers. On the other hand, the devoicing of sonorants after voiceless obstruents, in forms such as *cry* [kɾaj] and *plate* [pl̥et], is described as a post-lexical rule, where the output is gradient and variable. Kiparsky notes that the devoicing is not necessarily complete. The post-lexical status and gradient output of this rule lead us to wonder if it might not be more insightfully analyzed as a phonetic rule, rather than a post-lexical feature changing rule.

An alternative analysis would be to assume that sonorants remain unspecified for the feature Voice at the output of the phonology. Unless there is evidence of phonological reference to the voicing specification of sonorants, we need not necessarily assume that they receive default values for the feature Voice. Since obstruents contrast for voicing, we assume that they are specified as either [+voice] or [-voice] at the output of the phonology. Note that we cannot conclude that all segments which do not contrast for voicing remain unspecified. In English vowels are voiced. They do not appear to be affected by context in the way that sonorants can be; let us assume that vowels are specified as [+voice] (presumably due to a default fill-in rule, perhaps due to a requirement on syllable nuclei) by the output of the phonology. Following these assumptions about the phonological specification of these classes of segments with respect to the feature Voice, we can account for the gradient voicing of sonorants in clusters through phonetic interpolation. Sonorants, being unspecified for Voice at the output of the phonology, would then receive quantitative levels of voicing due to the phonetic context, as exemplified in (13). Let us assume for the sake of the discussion that the relevant phonetic parameter is whether the vocal cords are vibrating or not.

(13)

Phonological Output:		k	r	a	i		p	l	e	t
		-V	+V+V				-V	+V	-V	
Phonetic Targets:	vibration									
	no vibration									
Phonetic Interpolation:	vibration									
	no vibration									

This approach accounts directly for the kind of gradience observed in the realization of voicing of such segments, although there are additional issues that would need to be addressed to provide a complete analysis. A similar account could be proposed for the realization of voicing in sonorants in Russian. Kiparsky describes in detail the gradient effects of voicing in the sonorants. To my knowledge, there are no phonological rules of Russian that crucially make reference to voicing specifications of sonorants in Russian and thus there is no reason to assume that these segments necessarily receive default specifications in the phonology.

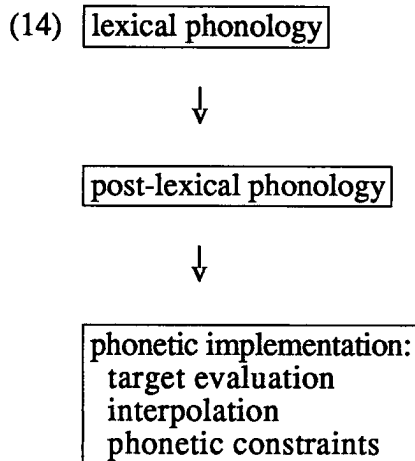
Such an analysis accounts directly for the observed gradience and in this respect is more adequate than an analysis which assumes feature changing, which would be expected to result in categorial rather than gradient outputs. Consider for a moment other possible accounts. Assume for the moment that the phonetic representation consists of several discrete values along a continuum, such as proposed by Anderson for the feature Nasal, thus voiced obstruents might be [1voice], voiceless obstruents might be [0voice] and sonorants might be [.5voice]. Such an analysis might be descriptively adequate, but it would miss the point that unlike the voicing specification for voiced and voiceless obstruents, the voicing specification of sonorants does not matter to the phonology. Also it would not account for the fact that sonorant voicing values are not always [.5voice], but rather are determined by context. Such values would, in effect, be an artifact of the analysis. Another view of phonetic implementation is that phonetic output is variable or indeterminate. This predicts that there is no systematic relationship between the phonological and phonetic contexts and the observed output. Although it does appear to be the case that some variability exists in phonetic output (that some limited range of values is possible along any particular phonetic dimension), to assume that there is no systematic patterning would be theoretically uninteresting as well as empirically inadequate.

Another case discussed by Kiparsky, of particular interest here, is the case of Nasal Harmony in Guaraní. It has been widely observed that there are long distance spreading effects of nasalization in Guaraní. Of interest to us here is the fact that some of these effects appear to be categorial, whereas some are gradient. Kiparsky again proposes these effects are the result of the lexical and post-lexical application of the same rule. It is the class of unstressed continuants which result in gradient effects. This is a class of segments which characteristically does not contrast for the feature Nasal cross-linguistically. There does not appear to be evidence of the nasal specification of these segments playing a role in the phonology. It seems plausible that this class

of segments remains unspecified for the feature Nasal and that these segments receive quantitative levels of nasalization through phonetic interpolation. An analysis along these lines will be proposed for the case of Sundanese nasalization, as discussed in Chapter 3.

To draw firmer conclusions, each of these cases would need to be examined in greater detail, including the study of relevant phonetic data; but these cases are suggestive and support the view that gradience is the result of phonetic implementation.

At this point it might be useful to consider a schematic representation of the grammar, presented in (14).



The implication of this model is that there should be interaction between lexical phonological rules and morphological ones, but not between post-lexical rules and lexical ones, nor between the phonetic implementation and the phonological rules. This means that rules which manipulate discrete and timeless units are not interleaved with those which manipulate quantitative values. Yet following the model of Pierrehumbert and Beckman (1988), where phonetic implementation adds information rather than replaces it, it is not impossible that phonological rules follow phonetic ones. Some cases of what appear to be such an ordering paradox have been cited in the literature, e.g. Anderson (1975). This is also the case in those dialects of American English in which flapping (an allophonic rule) follows vowel lengthening (assumed to be a phonetic process), resulting in the voicing contrast being maintained through a vowel length difference in such examples as *latter* /lætə/ [læɾə] and *ladder* /lædə/ [læ:rə].

1.5. The feature Nasal

There are various possible ways of studying the issues outlined above with respect to the nature of the mapping from phonology to phonetics. One way is to consider the behavior of a single feature within both the phonology and the phonetics. Pierrehumbert's work on intonation was ground breaking in the study of the mapping from phonology to phonetics, yet it is still an open question to what degree the specifics of Pierrehumbert's approach carry over to the mapping of a segmental feature. The detailed study of the mapping of a segmental feature will complement our understanding of implementation based on intonation.

Some features are better suited to such an undertaking than others. The type of case best suited to the present study would be one where both the phonological and phonetic functioning of the feature are well-understood, where the mapping is understood to be a direct one, and where the feature functions independently from other features articulatorily. I have chosen the feature Nasal for this purpose.

In both phonologically and phonetically motivated feature systems, there is assumed to be a single feature Nasal. In SPE, the feature Nasal is defined as follows:

4.7.1 Nasal-Nonnasal

Nasal sounds are produced with a lowered velum which allows the air to escape through the nose; nonnasal sounds are produced with a raised velum so that the air from the lungs can escape only through the mouth. (p. 316)

As with most of the feature definitions in SPE, this is an articulatory definition. Phonetically, the feature Nasal can be considered from at least three points of view: articulation/aerodynamics, acoustics, and perception. From the point of view of articulation and aerodynamics, it is clear that the result of the feature Nasal is a single process and can be considered as a single feature in the phonetics. Even in terms of the physical output, although a range of muscles are involved, it is clear that what is linguistically relevant is the size of the velopharyngeal opening. In this study, I will consider Nasal from an aerodynamic point of view. The reasons for this will be discussed in Chapter 2.

Phonologically the feature Nasal is believed to behave in a binary fashion; a segment may be specified as [+nasal] or [-nasal] (or remain unspecified). There is one putative example of a three-way categorial distinction for Nasal. Chinantec is described as having three surface levels of nasalization, but Ladefoged (1971) has argued that this contrast may be derived, with one case having an underlying nasal consonant; therefore this case does not necessarily provide evidence of either a non-binary distinction for Nasal or an intermediate level of representation which remaps a binary phonological distinction.

The feature Nasal may play a distinctive role phonologically in consonants and/or vowels. In consonants, it is an extremely common distinctive feature in the languages of the world (see Maddieson 1984); it is not an uncommon distinctive feature for vowels. Additionally, allophonic processes involving the feature Nasal are pervasive throughout the world's languages (see Cohn 1987). Most typically, vowels are nasalized by a neighboring nasal. Thus Nasal can be studied in a range of contexts.

A [+nasal] specification on a segment may cause both local and long distance effects on neighboring segments. Furthermore, the nature of these effects seems to vary. Although they are usually described phonologically, it appears likely that these effects are in some cases phonetic, due to their gradient nature.

Thus the feature Nasal seems to be an accessible place to start to examine the nature of the mapping from phonology to phonetics. It is not assumed that all aspects of this study will generalize to other features, but it is hoped that the general approach will.

A major question in the nature of the mapping from phonology to phonetics is how the different possible uses of the feature within the phonological system are reflected in its phonetic

realization. In order to address this aspect of the study, I have chosen three languages which differ in their phonological use of the feature Nasal: English, French, and Sundanese.

(1) In English, the feature Nasal is distinctive in [-continuant] consonants, but not vowels or [+continuant] segments. This is a very common use of the feature Nasal in a phonological inventory, and is perhaps the most common case. English also provides what is assumed to be a fairly standard case of contextual nasalization: there is said to be a phonological rule of anticipatory nasalization: $V \rightarrow \tilde{V} / _ N$, e.g. *dean* /din/ [dĩn]. Additionally, from previous phonetic studies (e.g. Kent et al. 1974, Al-Bamerni 1983, Boisen 1986 and Vaissière 1988), it is clear that there are both anticipatory and carryover phonetic effects of nasalization in English.

(2) In French, the feature Nasal is distinctive in [-continuant] consonants, e.g. /d/ vs. /n/ *dé* /de/ 'dice' vs. *nez* /ne/ 'nose'. There is also a surface contrast between oral and nasal vowels, e.g. *pas* /pa/ 'step' vs. *pan* /pã/ 'section'.

Although under some analyses, the nasal vowels of French are argued to be derived from underlying vowel-nasal sequences (e.g. Dell 1970, Schane 1968, Prunet 1986), what is relevant here is that there is clearly a surface phonological contrast. Thus the feature Nasal is distinctive in the output from the phonology for both stops and vowels (but not [+continuant] consonants). Additionally, there is contextual nasalization (Rochette 1973, Zerling 1984, Benguerel et al. 1977a & b, and Botharel, Simon, Wioland, Zerling 1986, Cohn 1988), which is presumed to be a purely phonetic effect.

(3) Sundanese is a case often cited in the phonological literature as having long distance spreading of nasalization. The feature Nasal is distinctive in [-continuant] consonants (stops), but not vowels or [+continuant] consonants, e.g. /d/ vs. /n/ *kadal* /kadal/ 'ground lizard' vs. *kana* /kana/ 'for the purpose'. Thus in terms of the feature Nasal's role in the phonological inventory, it is like English. But there is also progressive long distance spreading of nasalization through vowels and laryngeal segments, e.g. *nyiar* /niar/ [nĩãr] 'seek, active'. This spreading can continue through several segments until it is blocked by a non-nasal, supralaryngeal consonant (Robins 1957). This will be shown to be a phonological rule by its cyclic application.

These three languages differ in their phonological use of the feature Nasal, each representing a quite common pattern of the feature Nasal cross-linguistically. This choice of languages will enable us to address the question of how the phonological use of the feature affects its phonetic realization.

1.6. The role of variability

In the phonetic literature, there is much discussion of "variability" and "variation" (e.g. Al-Bamerni 1983, Kent 1983, Pierrehumbert and Beckman 1988). Both the terms "variable" and "variation" imply a lack of predictability and regularity in the observed phenomena. Yet in the phonetic literature, these terms are often used to describe a range of observable phonetic phenomena, independent from the assumed source of this range of observed behavior. This results, at times, in a rather anomalous usage of these terms, such as "systematic" or "predictable" variability. I believe that this sort of usage results from the fact that much phonetic variation has

been discussed without considering the role of context and therefore without trying to determine the predictable aspects of the observed phenomenon.

Not only is this a somewhat odd usage, but it masks an important distinction that needs to be made. In the study of any phonetic property, one almost always observes a range of phenomena, but there are at least two sources for this range of phenomena. Some of it is systematic, and predictable, due to phonological context, structural properties of the utterance, rate of speech and so forth. In the usage adopted here, this is not variability. On the other hand, one often observes true variability, that is a difference of phonetic realization in the identical phonological contexts elicited under comparable conditions. We need to distinguish between systematic differences (whether accounted for phonetically, phonologically, or paralinguistically) and those which are unpredictable. The term "variability" will be reserved for a range of observed phonetic behavior which is not systematic or predictable. Note that in the case of what appears to be variability, it is always possible that some factor not identified accounts for the range of behavior.

It is one of the premises of this study that much of what has often been assumed to be "phonetic variability" follows directly from linguistically conditioned factors. It is hypothesized that true variability is allowed precisely where there is no phonological contrast, in other words, where it does not "matter". We return to the issue of variability in Chapter 5, where it will be observed that there is more variability for the speakers of English under investigation than those of the other languages.

1.7. Organization of the study

In this chapter, the background has been laid out for the remainder of the study. The target-interpolation model has been proposed as a starting point for a model to account for the implementation of the feature Nasal. In the subsequent chapters, this model will be expanded and modified to account for the data of Sundanese, French and English.

Before turning to the structure of the remaining chapters, a few comments should be made regarding what this study is and is not about. The central approach in this study is the analysis of phonetic data, using phonological principles, in an attempt to first tease apart phonological and phonetic behavior and then study the nature of the mapping or the derivation from the phonology to the phonetics. This is similar to what Liberman (1983) terms the "hybrid approach".

One thing this study is not concerned with is the more physical level of detail, such as velum lowering that does not result in velo-pharyngeal opening. Only actual opening results in the perception of nasalization. The position taken here is that movement effects that are perceptible are potentially linguistic.

Second, in this study, we investigate the implementation of the feature Nasal. Implicit in this study is the feature Nasal's coordination with other features, yet this is not the focus of the study. Other recent studies of the feature Nasal focus more directly on the issue of coordination, notably Huffman (1989) and Krakow (1989), and the reader is referred there for more detailed discussion of the coordination of the feature Nasal.

Third, a complete theory of the mapping from phonology to phonetics includes the derivation of both time and space from abstract units into real quantitative values. In this study, more

emphasis is given to the mapping of space than to time. Many of the effects observed here are tied to more abstract timing, that is timing relative to segments. Segments are defined by the behavior of other features which tend to change in a more rapid manner than the feature Nasal, such as voicing and oral closure. (In this sense the coordination of the feature Nasal is examined, but at a fairly abstract level.) Specifics of segmentation are discussed in Chapter 2. Of course time must be incorporated, but a fully articulated model will not be offered.

The structure of the remaining chapters is as follows. In Chapter 2, methodology is discussed, including description of the apparatus used for data collection and method of analysis. In Chapter 3, we turn to the data, looking at the facts of nasalization in Sundanese. It is observed that blocking effects of the phonological rule of Nasal Spread (segments which prevent further spreading of the feature Nasal) must be accounted for by a general principle of feature co-occurrence rather than redundant feature specification, in order to account for the phonetic facts of nasalization. The phonetic facts of nasalization of sonorants are examined in some detail. In Chapter 4, we turn to the facts of French, where a wide range of possible contexts of nasal-oral sequences are studied. In order to account for the observed patterns, certain modifications are proposed to the target-interpolation model, including assigning inherent duration to targets and developing the role of phonetic constraints. In Chapter 5, we turn to the data of English, where again a range of contexts of nasal-oral sequences are studied. It is observed that the facts are basically compatible with the model proposed in Chapter 4, although variability must be taken into account. In Chapter 6, the concluding chapter, some comparison between the three languages is presented, the proposed model is discussed, and implications of the analysis are considered.

CHAPTER 2 METHODOLOGY

In this chapter, both general issues of methodology and specifics of data collection and analysis are discussed. The basic approach taken in this study is phonological, but a detailed, systematic analysis of the phonetic facts is also essential.

2.1. General issues

2.1.1. Role of phonetic data

The most basic way in which phonetic data are important to the study of phonology and its interaction with phonetics is to distinguish gradient from non-gradient output. Hearers perceive sounds categorically, that is we tend to impose categories on them. (See Repp 1983 and Studdert-Kennedy 1976 for discussion of the theory of categorical perception.) As discussed in Chapter 1, phonetic processes are often misanalyzed as phonological. I believe that this is due in part to the tendency that hearers (and researchers) have to impose a categorial interpretation on something which involves gradience. Thus in the example of vowel quality in [h] discussed in Chapter 1, hearers are not sensitive to the continually changing formant structure. It is precisely in the task of sorting out the difference between phonetic and phonological processes that the use of phonetic data is essential. Such things can not be sorted out with careful listening alone. Phonetic data give insight into other aspects of the rule system as well as phonological representations. Take again the case of vowel quality in [h]. Based on the observed gradient behavior of the formants during the duration of the [h], a specific claim is made about the phonological representation, that there is not necessarily full specification of feature values leaving the phonology (Keating 1988b). A similar kind of argument will be made in Chapter 3 with respect to nasalization in Sundanese.

2.1.2. Phonological methodology

A pervasive problem in much of the previous work on nasalization has been oversimplification of the range of data that needs to be considered. Phonological methodology requires a comprehensive consideration of logically possible environments. It is only when all the possibilities have been considered that an adequate analysis of the phonological facts can be constructed. The view taken in this study is that neither the phonology nor the phonetics can be understood without appropriate consideration of a full range of relevant environments.

The phonetic realization of any particular phonological feature is likely to be quite complex. It would be naive to assume that something which is part of a complex phonological system would not be equally, or more, complex in its physical implementation. The goal then is not to discover that the phonetics of nasalization is straightforward, but rather to be able to sort out which part of the observed complexity follows from the phonology. To be able to show this connection, an in-depth understanding of the phonology is necessary. Aspects of the phonology which are likely to have an important role to play include the following: stress, syllable structure, vowel quality and the interaction of Nasal with both Voice and Continuant. An understanding of these aspects of the phonology must precede any attempt to characterize the phonetic output. It is only by considering each of the relevant parameters in a controlled way that a cumulative picture of the interaction of the phonology and phonetics can be drawn. Morphological composition may also play a role, as there

may be boundary effects on rule application (e.g. certain morphological boundaries may block the application of a particular rule).

For each of the three languages under investigation, careful study of the phonology (and where relevant, morphology) was undertaken. In the case of both French and English, the extensive description and analysis of the phonology and morphology in the literature were consulted. In the case of Sundanese, the previous work is much more limited; in order to come to an adequate understanding of the both the phonology and morphology, field work with a native speaker was undertaken.

As an indication of the kind of consideration that is relevant, consider an example from English: the allophonic patterns in English /nt/ and /nd/ clusters (cf. Malécot 1960, Kahn 1976, Zue and Laferriere 1979). One might assume that these clusters were the same except for the underlying difference in voicing (which might be expected to affect the duration of the preceding vowel and/or nasal consonant), yet this is not the case. In some ways, a nasal consonant acts as if it were not there in an /nt/ cluster. It has been observed that the /n/ is sometimes deleted (or at least greatly shortened) in the /nt/ clusters. Thus the nasalization of the preceding vowel becomes the most salient cue to the distinction between such pairs as *cat* [kæt] and *can't* [kæ̃t]. (It is not clear how pervasively the /n/ is completely deleted in these cases. There appears to be dialect differences as well as speaker variation.) There is no similar tendency for the deletion of the nasal consonant in /nd/ clusters. Relating to this, Kahn observes that while pairs such as *ladder* and *latter* can be homophonous, pairs such as *sender* and *center* cannot. Following Kahn's discussion of the behavior of Flapping in such environments (Kahn 1976, p. 94), we might expect at least three pronunciations of *center* in contrast to one for *sender*.

- | | | | | | |
|--------|---------------|---------------|----------|--------------------|---------------------------------------|
| (1) a. | <i>sender</i> | | [sɛ̃ndə] | | |
| | b. | <i>center</i> | i. | [sɛ̃nt ə] | careful speech, Nasalization |
| | | | ii. | [sɛ̃rə] | Nasalization, n-Deletion and Flapping |
| | | | iii. | [sɛ̃nə] ([sɛ̃r̩ə]) | |

In the case of the /nd/ cluster (1a), there is nasalization of the preceding vowel, but no weakening or loss of the nasal, therefore the environment for Flapping (that is a preceding [-consonantal] segment, see Kahn) is not met. In the case of the /nt/ cluster, if the nasal consonant is not deleted, the environment for Flapping is not met (1bi); but if the nasal consonant is deleted, then Flapping applies (1bii). Kahn describes a third possible pronunciation, with a medial nasal (or perhaps a nasalized flap). (Kahn does not offer a derivation of such forms; an appropriate derivation depends on the specific rules posited.) Both rate of speech and speaker differences will lead to different realizations of these forms and will potentially result in different effects on nasalization. The conclusion from this is not that the data are hopelessly complex, but rather that care must be taken to observe what the actual patterns of allophony are.

Consideration of these kinds of intricate interactions of allophonic rules is central to being able to tease apart relevant environments with respect to nasalization. It is not possible to consider

fully all such issues for each of three languages; thus only certain variables will be considered and the others will be controlled for. Ultimately, one wants to observe all of these effects in connected speech, but it is essential to have a clear working understanding of the basic system before more complex data are considered, thus the primary focus of this study will be single words and in some cases phrases. All forms studied are real utterances in the respective language.

Of primary interest in this study is how nasal and non-nasal segments affect each other. In each case, systematic minimal sets were constructed. For example, for each form with a nasal segment, a minimally contrasting oral form was also recorded. Representative segments were selected for each segment type. For consonants, wherever possible, coronal segments were used. This has several advantages. Any effect of varying place of articulation was avoided (for discussion of effects of place of articulation on nasalization, see Künzel 1979). While stops, nasals, and fricatives characteristically occur at more than one place of articulation within a language's phonemic inventory, location of other consonants is more restricted. The greatest number of manners of articulation occur among the coronals. The front of the tongue, involved in coronal articulations, is assumed also to function quite independently from the velum (whereas the back of the tongue is less independent). Labial articulations are assumed to be completely independent from the velum as well, but were avoided, in part, because of potential complications with the instrumental techniques used in this study. The choice of vowels was greatly restricted, in order to control for effects from degree of oral constriction (discussed below) and from inherent duration differences. In each language, the vowels studied were somewhat different, but for the most part mid vowels were used. Syllable structure and stress were controlled for as much as possible, although in a few cases these were systematically varied. Following these general guidelines, a word list was constructed for each of the three languages. The word lists appear in the Appendix. Issues relating to the construction of the word lists for each particular language will be discussed in the relevant chapters.

2.2. Data collection

In this study, aerodynamic measurements were taken as an (indirect) indication of the behavior of the velum. Since aerodynamic information is intermediate between physiology and acoustics, it is a useful starting point for studying both the speaker and the hearer. Acoustic data were also used, for segmentation and duration measurements.

2.2.1. Choice of apparatus

Acoustic data alone are not sufficient for studying nasalization, since there is no single acoustic correlate (see House and Stevens 1956 and Huffman 1989 for discussion of the problems). Therefore, some sort of physiological data is also necessary. Several sorts of physiological methodology have been used to study nasalization, including x-ray studies, electromyography, fiberoptic techniques and aerodynamic techniques. All of these approaches are, in some sense, indirect, since it is not possible to observe the behavior of the velum in three dimensional space. There is extensive debate in the literature about the advantages and disadvantages of these different methods (for a discussion of some of this debate, see Al-Bamerni 1983, Boisen 1986, and Huffman 1989).

The nature of the present study, work with several speakers of different languages, and collection of multiple repetitions of many tokens, makes the choice of a non-invasive procedure of primary importance. The only completely non-invasive measures of nasalization are ones which involve collecting airflow; it was therefore determined that measuring nasal and oral flow would be the most appropriate method for the purpose of this study. Of the possible types of airflow systems available, the Rothenberg split-flow mask (see Rothenberg 1977) was chosen, due to availability, reliability and ease of calibration. Adequate and extensive data could be collected for most speakers and no discomfort was involved. The output appears to be quite consistent within and between sessions.

Nasal airflow is an indirect measure of the velum position. It is commonly assumed that velum position, or more precisely velo-pharyngeal opening, is the physical correlate of the feature Nasal (e.g. SPE), yet this does not mean that airflow is an inappropriate measure. One might think that, if usable, x-rays would be better, but these represent only two-dimensional space; the velum can start to lower without actually allowing air to escape. In such cases, there would be velum lowering with no perceptual cue of nasalization. This results in observations of movements that might or might not be linguistically relevant.

There are, however, some potential problems and limitations with using airflow which need to be considered:

(1) Degree of oral constriction. As described by House and Stevens (1956), degree of oral constriction has a very direct effect on nasal airflow. First, nasal airflow during a nasal consonant is greater than during a nasal vowel, since during the former, but not the latter, there is a complete oral closure. Second, it has been observed that vowel height affects the degree of nasal airflow. The higher the vowel, the greater the impedance in the oral tract, therefore the greater the nasal airflow. This has been termed the impedance effect (House and Stevens 1956). If one just observed raw nasal flow data, one might mistakenly assume that [i] / ___ [n] was "more" nasalized than the [a] / ___ [n], since the amount of nasal airflow was greater in the former. Such effects have been discussed for English, but clearly also occur with other languages. The general effect of this is fairly well understood and can be factored out by looking at relative nasal and oral airflow (as an indirect measure of both oral and velic constriction). This can also be controlled in a more direct way by limiting the choice of vowels used. The latter has been done here for each of the three languages.

(2) Inherent nasalization of low vowels. There is some mechanical linkage between the back of the tongue and the velum (Moll 1962, Ohala 1971, among others). When tongue position is low, velum position tends to be relatively lower. This can result in some low level nasal flow on low vowels in purely oral contexts. Taken together with the effect of oral constriction, low vowels are the least desirable object of study, since they potentially have some inherent nasalization and since in a nasal context (or if phonemically nasalized) they have the lowest level of nasal airflow. Because of this, low vowels were avoided in the present study.

(3) The effect of glottal state and differences in the size of glottal opening. This is most at issue in comparing voiced and voiceless sounds, since voiceless sounds often have much greater glottal openings than voiced ones. For this reason, voiceless sounds have been avoided for the most part, except for voiceless stops, which behave quite differently from voiced stops when

adjacent to a nasal; and /h/, which plays an interesting role in Sundanese. This effect can be factored out by recording both oral and nasal airflow and calculating a ratio of the two, since it can be assumed that glottal opening and rate of airflow will affect oral and nasal flow equally.

Both nasal and oral airflow were collected for this study, yet nasal flow alone, rather than a ratio (of nasal flow to total flow, represented as a percentage) was chosen as the primary form of data. A ratio can easily be calculated from the data as was indeed done in certain cases where this was important, but it was decided that, overall, nasal flow was the most useful indicator of the topics under study. For a comparison and discussion of the use of nasal flow vs. the use of a ratio, the reader is referred to Huffman (1989).

(4) There is one case where nasal airflow and other physiological measures make very different predictions as to what is "nasal", that is the case of a glottal stop or complete closure of the glottis. During a glottal stop, there is clearly no nasal airflow, but this is due to the fact that there is no air flowing through the glottis and does not necessarily indicate anything about velum position. Precisely such a case arises in Sundanese, where a glottal stop may occur between two nasalized vowels. There is no reason to suppose that the velum has actually raised and lowered in such cases. In such cases, position of the velum must be inferred from other types of evidence. This issue will arise with respect to nasalization in Sundanese, as discussed in Chapter 3.

Other concerns, specific to the particular type of airflow measurement system in use in this investigation, will be discussed in §2.2.3.

2.2.2. Speakers

In selecting speakers, careful consideration was given to dialect differences and only speakers of what was deemed to be the same dialect were used. This is an important restriction, since nasalization appears to be the kind of process that differs between closely related dialects; e.g., there have been differences observed (at least impressionistically) in the degree of nasalization between American and British English. As discussed in Chapter 1, there is also evidence that there are systematic differences between European French and Canadian French with respect to timing of nasalization during nasal vowels. A detailed comparison of such dialect differences would be an interesting matter for further study. But in this study, dialect effects will be controlled for as much as possible.

At least two speakers were recorded for each language (during one or two sessions). Data for two speakers for each of the three languages are presented here. Ideally, many more speakers would be analyzed in order to better understand the effects of individual speaker and dialect differences; but this was not feasible due to the size of the data set recorded for each speaker. Both male and female speakers were recorded. Due to specifics of the airflow measurement system, described in the next section, only speakers who had no facial hair and could read without glasses were used in this investigation. Additional description of speakers will be given in the relevant chapters.

2.2.3. The apparatus

A dual airflow system was used to measure both nasal and oral airflow. A simultaneous acoustic recording was also made. The airflow system used is a Glottal Enterprises split flow mask, which consists of a modified respiratory mask with attached nasal and oral transducers. As illustrated in (2), the mask covers the face from just below the mouth to the top of the nose, fitted with a plastic divider positioned against the upper lip. The outside perimeter of the mask is surrounded by rubber cushioning and the divider is covered with narrow weather stripping, replaced and adjusted for each speaker, to allow a snug fit and full separation of the two channels.

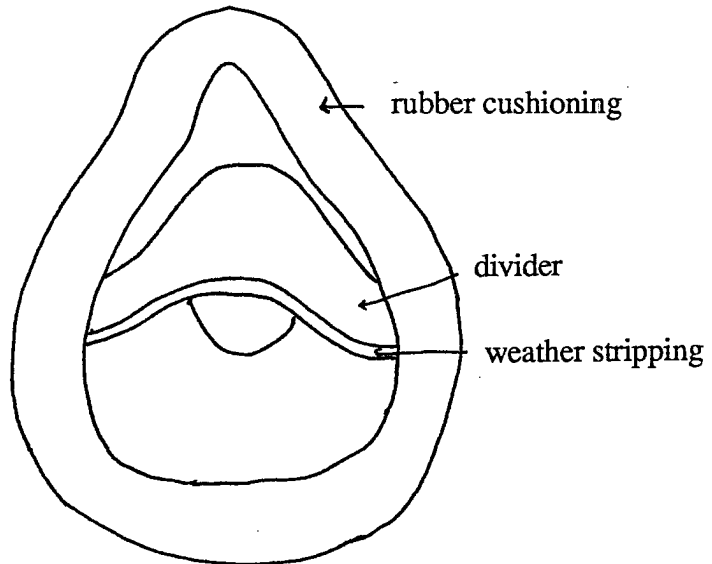
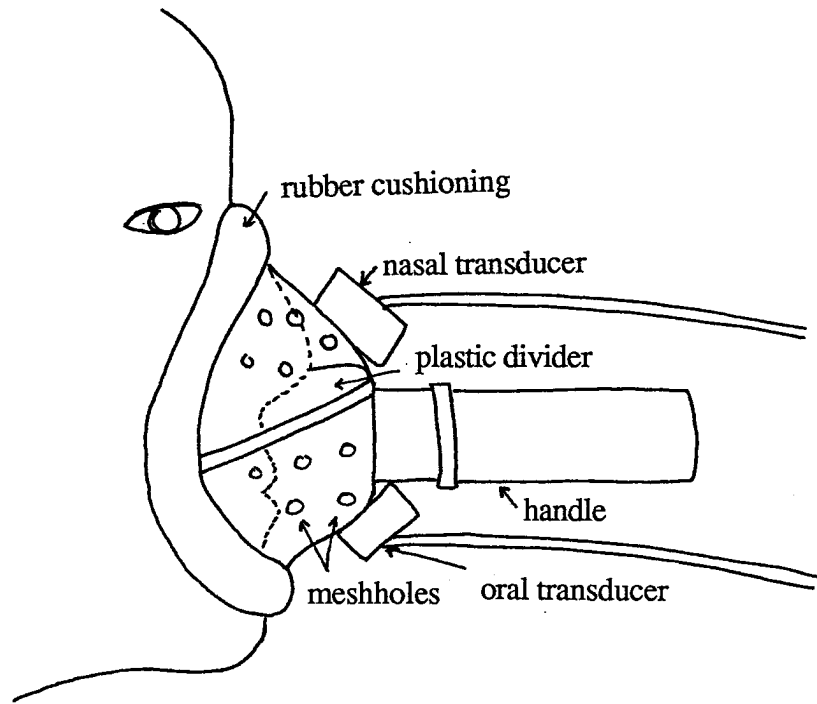
The mask itself is in two sizes, which are interchangeable, allowing a comfortable fit for a wide range of speakers. The mask has its own calibration system, allowing measurement of absolute amounts of flow, in milliliters per second. (See Rothenberg 1977 for discussion of the construction and additional specifications of the flow mask.)

Two methodological issues posed by this particular type of airflow measurement system are the following:

(1) One of the potential problems with most airflow measurement systems is leakage between the nasal and oral channels. There may be some extraneous flow on one or both of the channels. Such leakage was a serious problem for some speakers who were recorded. In these cases, data from these speakers were not analyzed and additional speakers were recorded. In some cases, recordings were achieved with virtually no leakage. In cases with minor leakage, the results can be factored out by comparing levels on minimally contrasting oral controls.

(2) A split flow system of the sort used here effectively creates a seal around the lower portion of the face. This may, to a mild degree, impede normal articulation. In the present study, for the most part, labial articulations were avoided, because it was believed that these were most likely to be affected. In general, subjects did not feel that the apparatus impeded their speech.

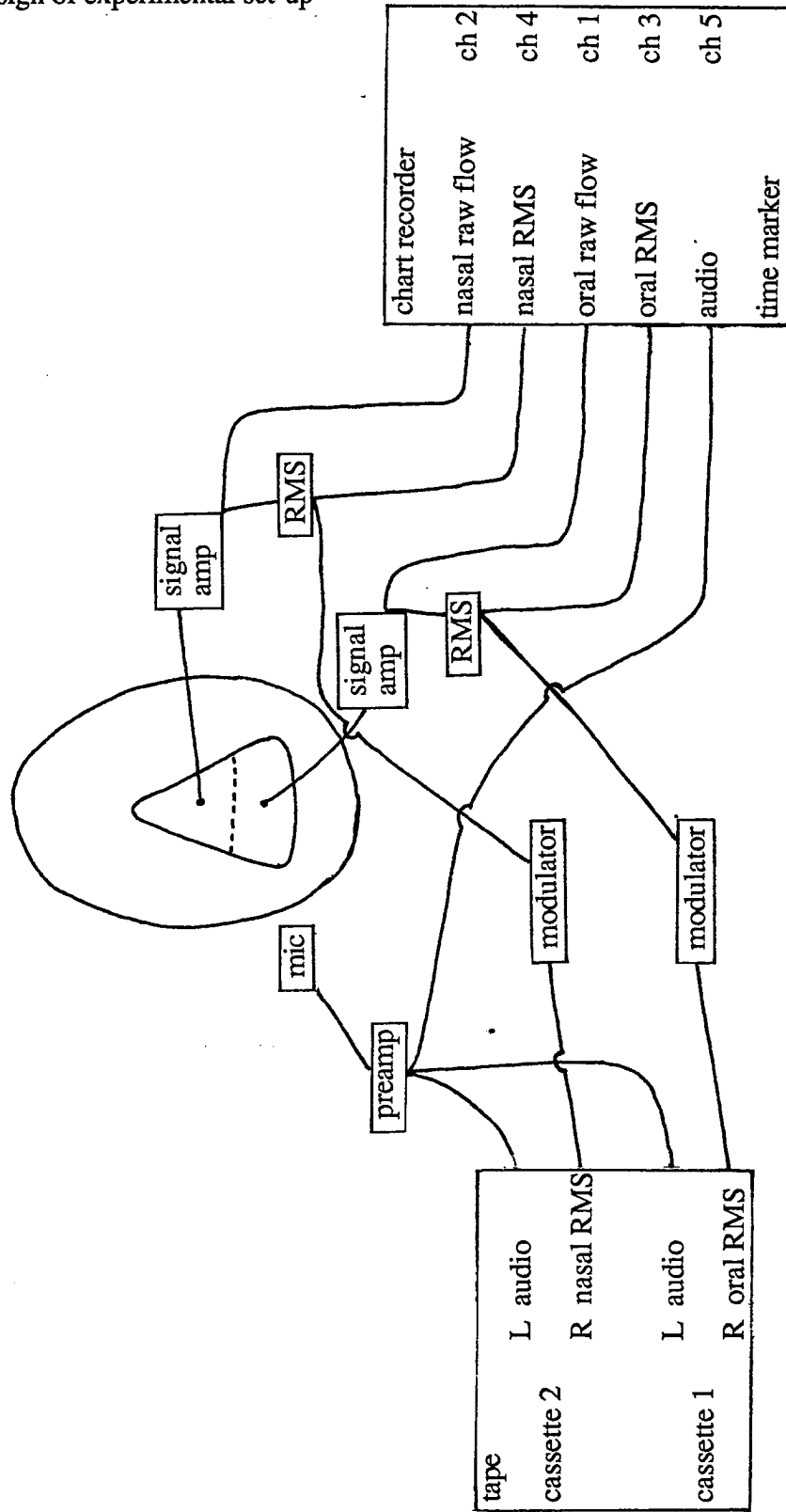
(2) The Glottal Enterprises split flow mask



2.2.4. The recording

The recording sessions were conducted in a sound-treated booth. At the beginning of each session, the speaker was shown the apparatus and asked to practice speaking through the mask. It was important that the speaker realize that s/he could breathe normally due to the mesh holes in both chambers and thus could speak in a normal fashion. The relevant word list was then checked with the speaker, to be sure that all the forms were familiar and acceptable. (In a few cases, a comparable form was substituted for one which was not found to be acceptable.) The speaker was asked to read the word list in an appropriate frame sentence (a frame in the relevant language which contained no nasal segments and both preceded and followed the test items with a stop consonant). The mask was held in place by the speaker, with enough pressure to create a seal on the face; adjustments to the mask were made when necessary to prevent leakage. Levels were set for the recording, with the speaker practicing the word list. Oral and nasal flow were recorded both on a Gould chart recorder and on audio tape. Because the raw signal is visually dominated by voicing, which is at higher frequencies than the airflows of interest, it was necessary to low-pass filter the data. A hardware RMS [Root Mean Squared] amplifier (for rectification and integration of the flow) was chosen for this purpose. Some consequences of this filtering process are discussed below. Five channels were printed out: raw oral and nasal flow, filtered oral and nasal flow, the audio waveform, as well as a timing signal. The chart recorder allowed simultaneous monitoring of the input for each channel and the printout was used as the primary source of data analysis. An FM recording was also made of the filtered oral and nasal flow with each flow channel recorded along with the audio signal, for additional analysis. Once everything was set and checked the word list was read at a comfortable rate of speech. The full word list was repeated at least five times by each speaker. The speaker was told that s/he could take a break at any point in the recording. After such a break, all levels were rechecked. At the end of each session, the system was calibrated, using a calibration unit specially designed for the mask which introduces known flow levels into the system. In this way, comparisons can be made between sessions and between speakers. The experimental setup is schematized in (3).

(3) Design of experimental set-up



As illustrated in (3), the oral and nasal flow were treated in a completely parallel fashion. Both were first passed through a signal amplifier (part of the Glottal Enterprises flow system). The nasal flow was printed out directly on paper through the chart recorder (Ch. 2); it was simultaneously filtered using an RMS chip with a time constant of 3.25 ms. The filtered flow was simultaneously printed out on paper (Ch. 4) and also modulated and recorded on the right channel of a cassette (Cassette 2). The oral flow was treated in a parallel fashion, with raw flow printed out on Ch. 1, filtered flow on Ch. 3, and filtered and modulated flow recorded on the right channel of Cassette 1. An audio recording was made using a microphone positioned close to the mask, in equal proximity to the oral and nasal chambers of the mask. In earlier recordings, a small condenser microphone was attached to the outside of the mask, positioned at the level of the divider between the two chambers, but problems emerged due to the sensitivity of the microphone to any small movements. In later recordings, this microphone was replaced by a studio type microphone in a stand, positioned at the side of the mask. In both cases, sound from both the oral and nasal chambers was recorded and only slight perturbations of the acoustic signal due to the mask were observed. (Since the audio recordings were used primarily for segmentation, the quality of the recordings was adequate for this study.) The audio signal was passed through a pre-amplifier and then recorded on the left channels of the two cassette tapes. Time markers and a centimeter by centimeter grid were also printed out by the chart recorder.

2.2.5. The data

Both the chart recorder print out and the tape recordings were available for analysis. Primary analysis was done on the chart recorder print out using the filtered nasal flow in conjunction with the filtered oral flow. Spectrograms were also made. In cases of difficult segmentation, the spectrograms were used. Tokens were labeled and segmented. Tokens were grouped by type and traced. We consider the form of the data in this section, taking examples from the French data. Issues of segmentation and data preparation are discussed in §2.3.2 and §2.3.3 respectively and issues of data interpretation are discussed in §2.4.

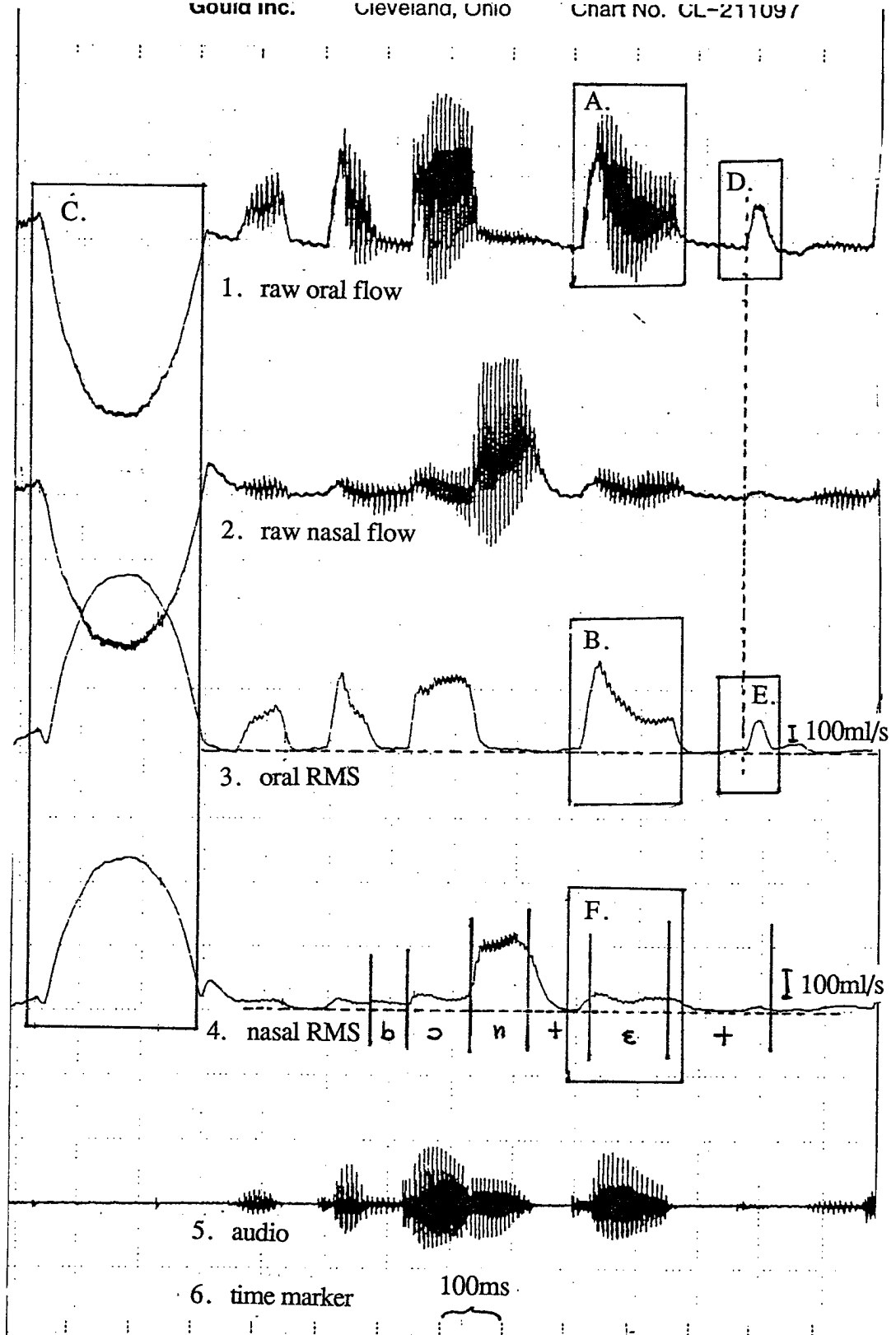
In (4), an example of the raw data is given. The five channels and time marker can be observed.

(4) Sample of chart recorder printout from Speaker F-F

Gould Inc.

Cleveland, Ohio

Chart No. CL-211097



The five channels, as described in (3), are labeled 1-5 respectively. The time markers are labeled as 6. The overall shape of the raw flow, on Channels 1 and 2, and filtered flow, on Channels 3 and 4, are quite similar, as seen by comparing, for example, the raw flow in Box A and the filtered flow in Box B. But in the case of the raw flow, the vibration from voicing is also present, making the interpretation of the amplitude of flow difficult. The filtered flow provides a much cleaner trace, which is more easily interpreted. Yet a few things need to be borne in mind. Since it is rectified, any negative flow is represented as positive. This can be seen most clearly by comparing the raw flow and the filtered flow for the inhalation, enclosed in Box C. We see that the raw flow, both oral and nasal is negative, but in the filtered flow, it is positive. For the most part, this is not problematic, since all sounds under investigation in this study involve an egressive flow source. The filtering is done over a window with a time constant of 3.25 ms. This results in a fairly smooth curve for most speakers, but some vibration is still observed for speakers with a low fundamental frequency. All measurements and tracings were made from the top of the curve, to ensure systematic measurement. There is a slight time lag introduced by the filtering. This can be seen by comparing the turning point of the release for the [t] in both the raw and filtered flow, shown in Boxes D and E respectively and connected with a vertical dashed line. The offset is on the order of 5-10 ms, within the range of error for segmentation; thus this slight offset does not pose a problem for the analysis. Finally, values very close to zero flow are slightly disturbed by RMS processing, since squaring results in all positive values. (See Huffman 1989 for discussion of this issue.) Very low levels of flow, then, are difficult to interpret. The potential false flow, together with the slight leakage observed for some speakers, is taken as noise in the data. For each speaker an effective baseline for nasal flow was set by looking at minimally contrasting cases, as described below.

The raw oral and nasal flow together equal 100% of the total airflow, but the four flow channels are scaled differently. The level of flow visually represented for each channel is not the same amount of physical flow; that is, the scale for amplitude of flow, measured in milliliters per second, is not the same for the oral and nasal channels (and is different for each speaker as well). The physical levels of flow can be determined by calibration of the system; the scales for this speaker are shown on the far right of this example. The ratio of the scale of oral flow to nasal flow for this particular speaker is about 1:2.

In this particular example, we see one token of the form *bonne tête* /bɔ̃n tɛt/ 'good head' said in the frame *dites _____ deux fois* 'say _____ two times' /dit ____ dø fwa/. (The /dø fwa/ has been cut off.) This has been segmented and labeled. Looking at the filtered nasal flow, we see what we will call negligible flow for all of the oral segments and a marked level of flow for the nasal consonant. An example from this particular speaker was chosen precisely because we wished to illustrate the artifacts due to some leakage of oral flow which can be observed on the nasal channel. As discussed in greater detail in §2.3.2, segmentation was carried out by comparing the oral and nasal flow, also using the audio signal where helpful. Spectrograms were made of all forms with potentially ambiguous segmentation, such as sequences involving adjacent vowels or vowels and [+continuant] segments. A zero flow line can be drawn by observing the points of true zero flow. Such zero lines have been drawn in, with dashed lines for both the oral and nasal filtered flow, in the example in (4). The horizontal line drawn in all the data is a zero flow line.

It can be seen that there is a certain amount of nasal flow above this zero line for "oral" segments in the example. This is the result of slight leakage of oral flow onto the nasal channel. The shape of this nasal flow parallels the oral flow as seen by comparing Box F with Box B. Because of this low level of leakage, as well as the slight offset from zero due to the RMS processing, an effective baseline needs to be determined. This procedure, along with other aspects of data preparation and analysis are discussed in the next section.

2.3. Data preparation and analysis

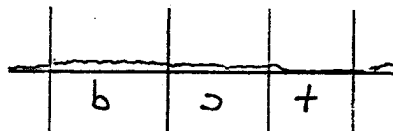
2.3.1. Setting an effective baseline

An effective baseline, an appropriate offset from the zero baseline to account for minor leakage of flow, needed to be set for each speaker, since the amount of leakage varied between speakers. An effective baseline was set for each speaker by comparing the filtered nasal flow in minimally contrasting forms, as illustrated for two speakers in (5).

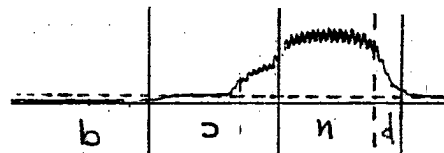
(5) Filtered nasal flow (Channel 4) for a pair of minimally contrasting forms for each of two speakers of French, showing the effective baseline

a. Speaker F-D

nasal flow of "oral" token
botte /bɔt/ [F-D 2]

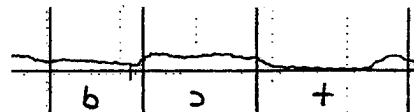


nasal flow of "nasal" token
bonne d(eux) /bɔ̃nd/ [F-D 2]

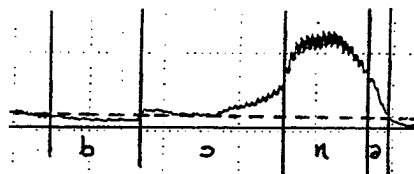


b. Speaker F-F

nasal flow of "oral" token
botte /bɔt/ [F-F 3]



nasal flow of "nasal" token
bonne /bɔ̃nə/ [F-F 3]



By comparing the level of nasal flow in an "oral" form, a form with known phonemically oral segments, with a minimally contrasting "nasal" form, a baseline for each speaker can be drawn, as indicated in (5) with a dashed line. In other words, we want to discount from the "nasal" token any amount of flow also observed in a minimally contrasting oral token. Applying this procedure, we see that there was more leakage for speaker F-F (5b) than for speaker F-D (5a). (The bracketed letters and numbers refer to speaker and token number.) In other words, there was somewhat more noise in the data of speaker F-F. In the data analyzed, these effective baselines

need to be borne in mind. (Such effective baselines are similar to the orality threshold defined by Huffman 1989, although she was also concerned with intrinsic segmental differences.)

2.3.2. Segmentation

Segmentation was done for all tokens. Segmentation is a central part of the methodology, since in some cases, decisions regarding the boundary between two segments directly affect the analysis of these segment types. In this section, I lay out the basic heuristics that I used for segmentation. These heuristics were applied to all three of the languages. All five channels of data, that is oral and nasal flow, both raw and filtered, as well as the audio signal were referred to in order to segment the filtered nasal flow trace of each token. The main criteria referred to for use in segmentation were changes in oral airflow and onset and offset of voicing. The presence or absence of nasal airflow was not used as a primary criteria, since this would result in circular definition of which segments were "nasal" or "oral". The one exception to this is the case of nasal consonant-oral voiced stop and oral voiced stop-nasal consonant sequences, as discussed below. As noted above, these criteria alone were not sufficient for segmentation of sonorant segments in many cases (vowel-vowel sequences, sonorant consonant-vowel sequences, and so forth). In these cases, spectrograms were used to aid in segmentation. The use of spectrographic information in segmentation is discussed in the next section.

In (6) the segmentation for the major classes of segments is summarized. The basis of segmentation for a sequence S_1S_2 is indicated with the S_1 along the vertical axis and S_2 along the horizontal axis:

(6) Summary of segmentation for major classes of segments

S1	S2	voiceless stops (T)	voiced stops (D)	nasal C's (N)	liquids (R)	glides (G)	oral vowel (V)	nasal vowel (Ṽ)
voiceless stops (T)		EF (SR)	EF (SR)	EF (SR)	na	PF	OV (SR)	OV (SR)
voiced stops (D)		EF (SR)	EF (SR)	(SR) ON	na	PF	OV (SR)	OV (SR)
nasal C's (N)		EV, specs	(EN)	spec	OF, spec	OF	OF	OF
liquids (R)		na	na	EF	na	CF, spec	CF, spec	CF, spec
glides (G)		na	na	EF	na	na	CF, spec	CF, spec
oral v's (V)		EF	EF	EF	CF, spec	CF, spec	CF, spec	CF, spec
nasal v's (Ṽ)		EF	EF	EF	CF, spec	CF, spec	CF, spec	CF, spec

- spec = spectrogram
- SR = end of burst or stop release
- OV = onset of periodic voicing
- EV = offset of periodic voicing
- OF = onset of oral flow
- EF = offset of oral flow, oral closure
- PF = peak of oral flow
- CF = change in amplitude of oral flow
- ON = onset of nasal flow
- EN = offset of nasal flow
- na = sequence not attested in corpus, or not under consideration

As summarized in (6), in cases where there is a significant change in oral flow, this was used as the primary criterion in segmentation. In cases such as NV, DV, VN, VD, the offset of oral airflow (EF) or onset of oral flow (OF) was taken to indicate the release oral closure or release respectively; this was taken as the boundary between the two segments. When the segment had a distinct release, as in the case of oral stops, the period of the release, as well as any aspiration, was segmented as part of the segment. (SR refers to the end of such a release.) In cases involving voiceless segments or aperiodic voicing during a burst, the onset of voicing (OV) or offset of voicing (EV) was also used for segmentation. For example, in the case of TV or TN, the onset of voicing was taken as the primary indicator of the segment boundary. In the case of a sequence of two sonorants (including both sonorant consonants and vowels), change in amplitude of oral flow (CF) as well as spectrographic information was used (spec). For the speakers of French studied in this investigation, a sequence of TG resulted in a voiceless glide, making segmentation following the above criteria difficult. In this case, peak oral flow (PF) was used as an additional criterion. Segmentation in the case of homorganic DN and ND sequences could not be made based on either changes in oral flow or onset or offset of voicing. When a DN sequence had an oral release, the

end of the release (SR) could be used. Otherwise, in these two cases, segmentation in effect is definitional, since these segments are differentiated only in term of presence or absence of nasal airflow, precisely the variable under investigation. In such cases, a tentative segment boundary only is indicated by a dashed line. Finally some segment-segment sequences either did not occur or were not relevant to the investigation (na). In Sundanese, segmentation of [h, ʔ] was also necessary, but these have not been included in the table, since their distribution was quite limited. In the case of [h], it occurred either intervocalically or before a nasal. Change in voicing as well as overall rate of airflow were used for the purpose of segmentation. In the case of [ʔ], the offset of oral airflow was used for segmentation (although in many cases, effects of glottalization could be seen in both the preceding and following vowel).

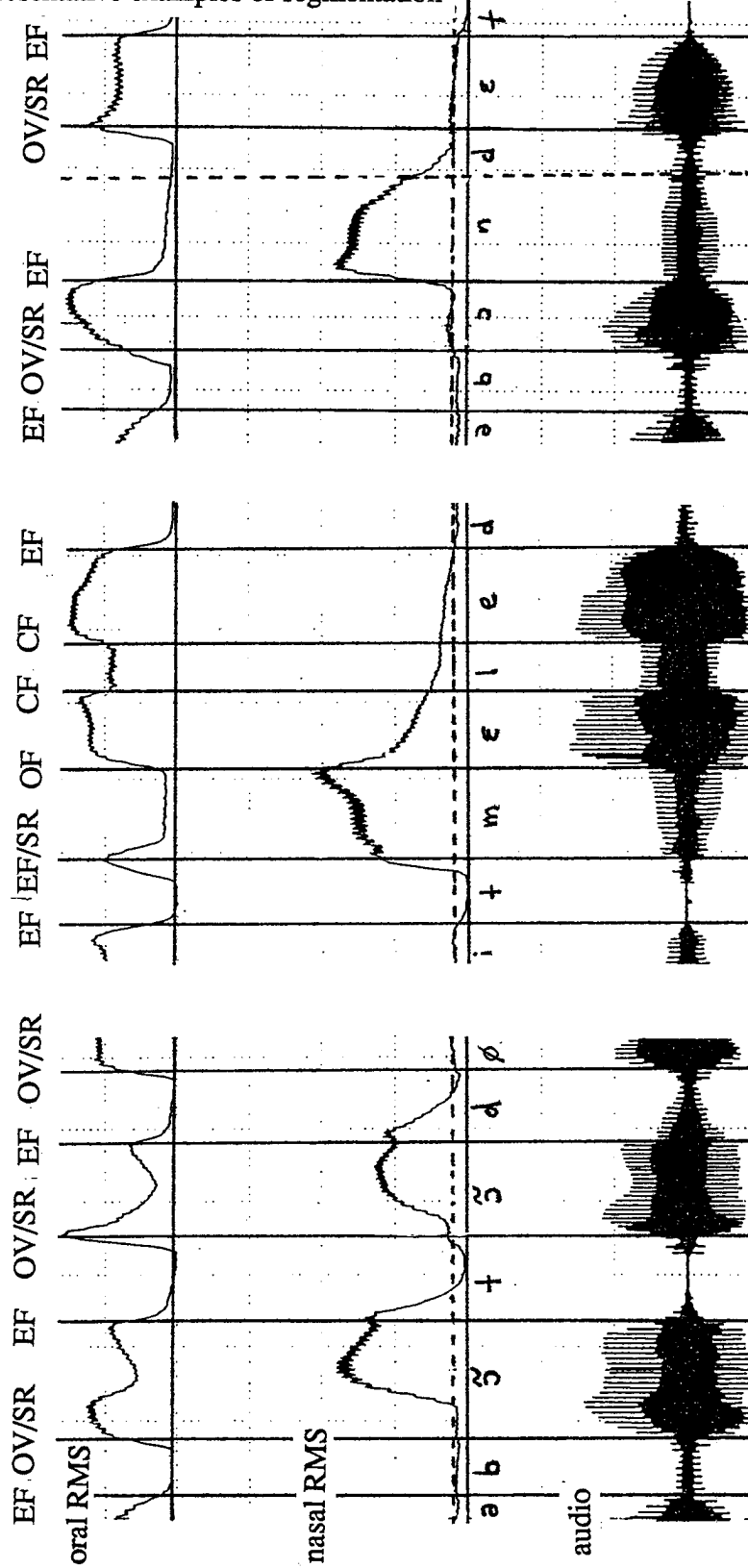
Representative examples of segmentation making reference to both oral and nasal airflow are presented in (7). We see three tokens including filtered oral and nasal airflow and audio signal, with segmentation indicated. The method of segmentation is indicated in the top of the figure, following the abbreviations presented in (6).

In (7a) *bon thon* /bɔ̃ tɔ̃/, we see an example of VD, $\check{V}D$ and $\check{V}T$ transitions, segmented based on offset of oral flow (EF) and examples of $D\check{V}$, $T\check{V}$, and DV transitions, segmented based on onset of periodic voicing and the end of the stop burst (OV/SR). We observe that the choice of the end of the stop burst rather than its beginning can affect what is determined to belong to the segment, as in the case of $T\check{V}$, when the release is about 20ms in duration.

In (7b) *mêler* /mɛler/, in addition to examples of VT and VD, we see an example of TN, marked by ER/SR. Here the difference between measuring from the release of the stop vs. the onset of voicing can be seen. The choice of the latter has the consequence for our analysis of saying that the oral-nasal transition occurs during the stop, not the following nasal consonant. We see in such cases that segmentation does have significant consequences for the analysis. The NV transition is segmented based on onset of flow (OF). The transition into and out of the [l] (VR and RV) in both cases can be segmented quite clearly by reference to change in oral flow (CF).

In (7c) *bonne dette* /bɔ̃n dɛt/, in addition to VD and DV transitions, we observe a VN transition, segmented based on offset of flow (EF) and a ND transition. This latter case, a homorganic nasal-voiced stop sequence is a particularly difficult one. As noted above, we can not appeal to changes in either oral airflow or voicing in such cases. Segmentation can only be based on nasal airflow at which point the segmentation is purely definitional. In such cases, a tentative segmentation is indicated only with a dashed line.

(7) Representative examples of segmentation



a. *bon thon*

b. *mêler*

c. *bonne dette*

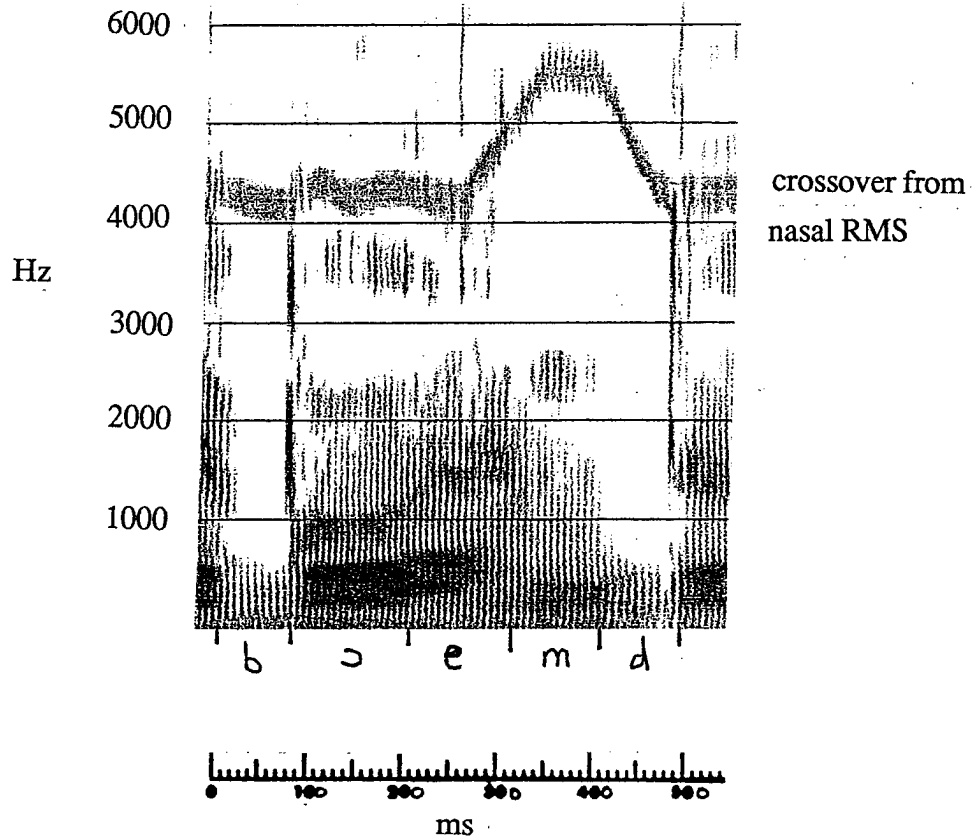
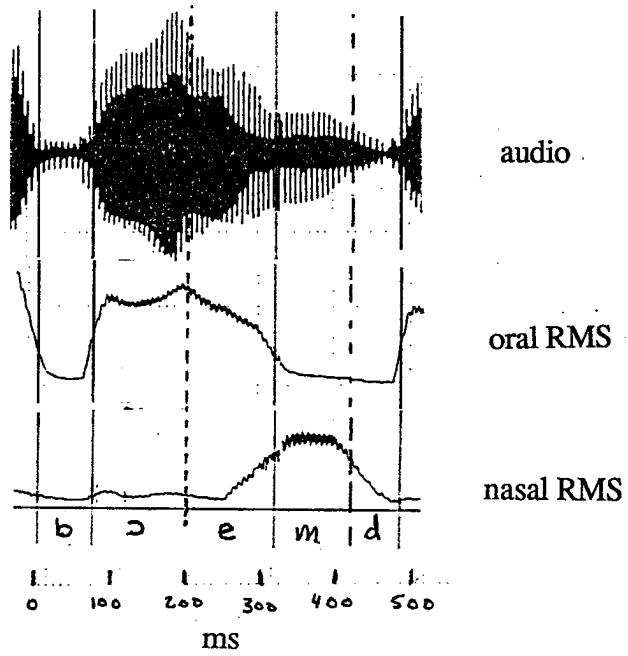
In conclusion, although in the subsequent discussion we focus on the filtered nasal flow traces, the segmentation of these tokens, in effect, incorporates additional relevant information from the other channels.

2.3.3. Segmentation with the spectrograph

As noted above and summarized in (6), spectrographic analysis was needed for segmentation in some cases. Wideband spectrograms were made using a Kay Digital Sona-Graph 7800. An unexpected consequence of the methodology was that there was some crossover from the right channels (the flow channels) onto the left channels (the audio channels) of the cassettes during recording. This resulted from the high intensity of the flow recording. This turned out to be a fortuitous result as this weak image of the flow (with a zero flow level around 4000 Hz, well above the range important for segmentation) greatly facilitated segmentation and comparison with the flow traces. Spectrograms were made in the range of 0-8000 Hz from the cassette containing the recording of nasal flow. An example is shown in (8) of the flow traces (filtered oral and nasal) and audio signal with the corresponding spectrogram for *Bohême* /bœem/ 'Bohemia'.

We see that it is not possible from the flow traces and audio signal alone to determine precisely the segmentation of the vowel-vowel sequence, although a good estimate can be made. The formant transitions between the vowels can be seen in the spectrogram and these were used to assist in segmentation in such cases. In cases where there was a smooth transition between two segments, the boundary was located in the middle of the transitional portion. Starting at about 4000 Hz, the echo of the nasal flow trace can be seen. Although very useful, this flow trace on the spectrogram is less precise than the flow trace printed out directly with the chart recorder, and therefore does not replace the use of the flow trace itself.

- (8) Example of spectrogram and corresponding flow trace for one token of Bohême /bœm-d/ 'Bohemia'

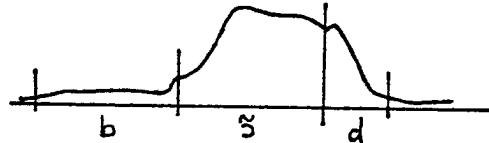


2.3.4. Tracing

Once segmentation was completed, all data were traced and grouped together by token, to allow comparison both between tokens and types. In (9), an example of five traced tokens for the form *bon d(eux)* /bʒ-d/ 'good' (m.) is presented for speaker F-D.

(9) Example of five traced tokens of /bʒ/ followed by the /d/ of the frame sentence for Speaker F-D, filtered nasal flow only (Channel 4)

a. [F-D 2]



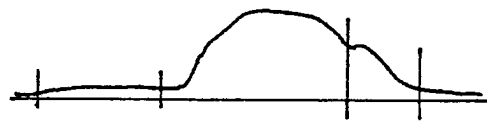
b. [F-D 3]



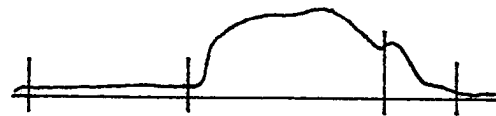
c. [F-D 4]



d. [F-D 5]



e. [F-D 6]



In this form, the /b/'s are oral as expected and the /ʒ/'s are significantly nasalized. The following /d/'s of the frame sentence are also nasalized during much of their duration, a fact that will be considered in Chapter 4. In this example and more generally, forms were very consistent across tokens. In most of the subsequent discussion, only the filtered nasal flow will be presented. In many cases, single representative tokens will be discussed.

2.4. Data interpretation

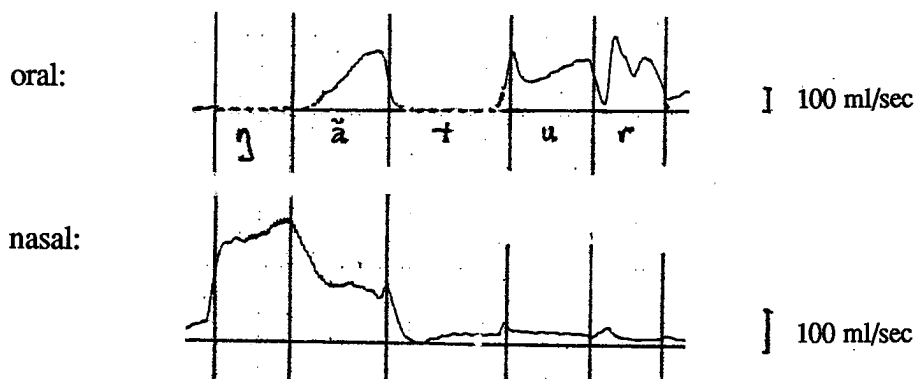
2.4.1. Abstraction away from the nasal flow traces

It was noted in §2.2, that there are certain senses in which nasal airflow is only an indirect indication of velum position. We turn now to the question of data interpretation with respect to the effect of oral constriction. In the subsequent discussion, we abstract away from the data in this regard; in this discussion we look at the data itself and the motivation for and nature of the abstraction. The effects of glottal state and overall rate of airflow, and effect of complete glottal closure are relevant to the analysis of the Sundanese data, but less directly relevant to the analysis of the French and English data, and therefore we put off a consideration of these cases until Chapter 3.

There are two ways in which oral constriction affects the rate of nasal airflow. The first, the most extreme, is the difference between a nasal consonant and a nasal or nasalized vowel.

Consider an example with both a nasal consonant and a nasalized vowel, as exemplified in the form /ɲatur/ [ɲãtur] 'arrange' (active) from Sundanese, where as discussed in Chapter 3, a vowel following a nasal consonant is nasalized. In this case, both the nasal consonant and following vowel are assumed to be specified as [+nasal] leaving the phonology.

(10) Filtered nasal and oral flow compared for [ɲãtur] [S-L 1] 'arrange' (active)

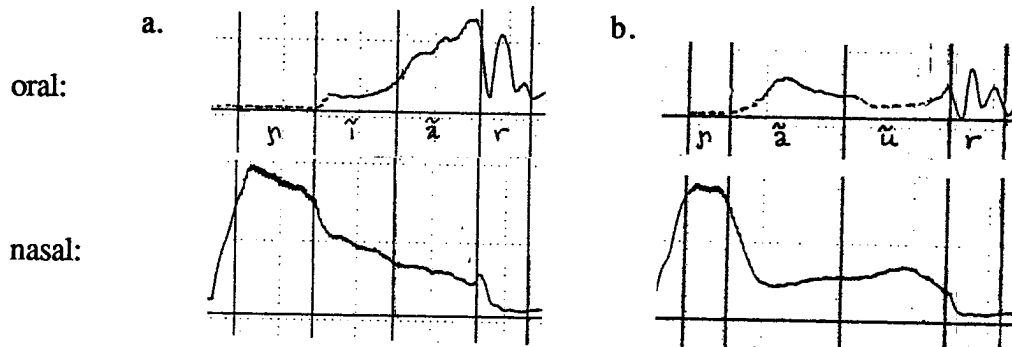


Looking first at the filtered nasal flow in (10), we observe substantial nasal flow on both [ɲ] and the following [ã], but not on any of the subsequent segments. This is as expected, if both [ɲ] and [ã] are specified as [+nasal] leaving the phonology. Yet we see a marked difference in the amplitude of nasal flow on these two segments. This difference in amplitude of nasal flow between the nasal consonant and the following vowel has a physical cause: during the nasal, all airflow is through the nasal cavity, whereas during the vowel, air flows out through both the oral and nasal cavities. This can be seen by comparing the nasal airflow with the oral airflow. As indicated on the scales on the right, the same visual level of flow does not indicate the same physical level of flow; rather the visual level of oral flow indicates approximately five thirds the physical amount of nasal flow.

As there is no oral flow during the oral closure of the nasal consonant, all air flowing through the glottis must escape through the nose and we observe therefore maximal nasal flow. During the transition between the [ɲ] and [ã], we see that the nasal flow decreases as the oral flow decreases. (The segment boundary is taken to be at the beginning of this transition, at the point of onset of oral flow, as described in the preceding section.) During the remainder of the vowel there is a significant amount of both oral and nasal flow. Note that during the following [t], there is neither oral nor nasal flow, as expected.

The other case where degree of oral constriction directly affects the rate of nasal airflow is with intermediate oral impedance – relative opening of the oral tract, which as discussed above differs significantly for high and low vowels, as well as back and front vowels. Consider again an example from Sundanese. In this case, we compare the forms [ɲĩãr] 'seek' (active) and [ɲãũr] 'say' (active) exemplified with both nasal and oral airflow in (11).

(11) Nasal and oral flow compared for [ɲf̄ār] 'seek' (active) [S-L 2]
and [ɲāũr] 'say' (active) [S-L 1]



Following the phonological rule of Nasal Spread, to be discussed in Chapter 3, we expect that the nasal consonant as well as both of the following vowels are specified as [+nasal] at the output of the phonology. Thus, after factoring out the effect of oral closure during the nasal consonant, we would expect to see comparable levels of nasal flow throughout the nasal consonant-vowel-vowel sequence, yet as seen by looking at the nasal flow traces, we see that in the first case (11a) there is a slight drop in nasal flow between the two vowels; whereas in the second case (11b) we see a slight rise in nasal flow between the two vowels. That this effect is due to the overall rate of airflow through the glottis in relation to the relative size of the oral opening can be seen by comparing oral and nasal flow as shown for these forms. Here we see an inverse relationship between oral and nasal flow, as expected. In (11a), due to close oral constriction for [f̄], oral flow is low and nasal flow is relatively high. For [ā] on the other hand, there is no oral constriction, therefore a high rate of oral flow and a relatively lower rate of nasal flow is observed. In (11b), the opposite effect obtains, since the oral constriction is greater for [ũ] than [ā].

The effects of oral constriction are purely physiological ones. These effects need to be understood so that we can interpret relative levels of nasal airflow across dissimilar contexts. In order to address the issues of primary interest in this study, we abstract away from these effects. This is informally done throughout the subsequent discussion both in terms of the aspects of the data to be accounted for and in terms of the specific rules proposed.

2.4.2. Plateaus and clines

In Chapter 1, we discussed both cline-like and plateau-like effects in the phonetics. It was argued that following a target-interpolation type model of phonetic implementation, we expect clines to arise, either as rapid transitions between segments with unlike phonological specifications, or as a result of phonetic interpolation across a phonologically unspecified span; whereas plateaus are the expected result of the interpretation of a phonological feature value. A segment phonologically specified for a particular feature is expected to exhibit that quality for a significant portion of its duration (Keating 1987, 1988a). Taking these assumptions as a starting point, we can use the difference between plateaus and clines in phonetic data as one source of

evidence for determining whether a particular process is the result of a phonological or phonetic process.

Yet we must be cautious in this endeavor. First it was observed that plateaus may result across phonologically unspecified spans, if there are specified like values on either side. Second, in many cases, we are required to abstract away from the data in the ways discussed in the preceding section, to determine if an observed pattern is a plateau or a cline. Thus in an abstract sense, portions of the flow traces presented above in (10) and (11) are concluded to consist of plateaus, e.g. [ŋã] in (10) is abstractly a plateau, as are [ɲĩã] and [ɲãũ] in (11). Under this abstraction, the observed rapid cline between [ŋ] and [ã] in (10) is an artifact of the data, whereas the observed rapid cline between [ã] and [t] is a result of the transition between a [+nasal] and following [-nasal] segment. In the subsequent discussion, we will also observe longer clines, throughout the duration of a segment or more, and in these cases this will be taken as evidence of a segment or a sequence of segments being unspecified for the feature Nasal. The distinction between plateaus and clines is an important one for the interpretation of phonetic data, but must be applied with care and caution.

This concludes the description of the preliminary analysis carried out for all data in the study. Additional analysis of various sorts done of subsets of the data, e.g. duration measurements, will be discussed in the relevant chapters.

CHAPTER 3 SUNDANESE

The case of nasalization in Sundanese has been widely discussed in the phonological literature, both with respect to observed long distance spreading effects and certain apparent ordering paradoxes (see, in particular, Robins 1957, Anderson 1972, and Cohn 1989). It is shown below that the issues from the Sundanese facts that had been taken to be problematic follow quite directly from certain independently motivated phonological mechanisms, including the interleaving of phonology and morphology as the correct account of the phonological cycle and the hierarchical relationship among phonological features. This does not, however, mean that the case of nasalization in Sundanese is not of theoretical interest. A systematic study of both the phonology and phonetics of nasalization in Sundanese reveals important generalizations about the nature of phonological blocking in harmony-type rules. The data also give insight into the realization of phonological vs. phonetic processes. It is a particularly useful case for such discussion, because there is independent evidence for the particular processes being phonological or phonetic respectively. Each of these issues will be taken up in turn.

The structure of this chapter is as follows: In §3.1, a discussion of the issue of phonological harmony blocking is presented. In §3.2, the data of Sundanese collected for this study are described. In §3.3, a basic analysis of both the phonological and phonetic facts of Sundanese is proposed. In §3.4 and §3.5, several aspects of the analysis are more fully developed. In §3.6, the issue of phonetic vs. phonological rules is discussed. In §3.7, a brief summary of the primary observations and conclusions of the chapter is provided.

3.1. The nature of phonological blocking effects

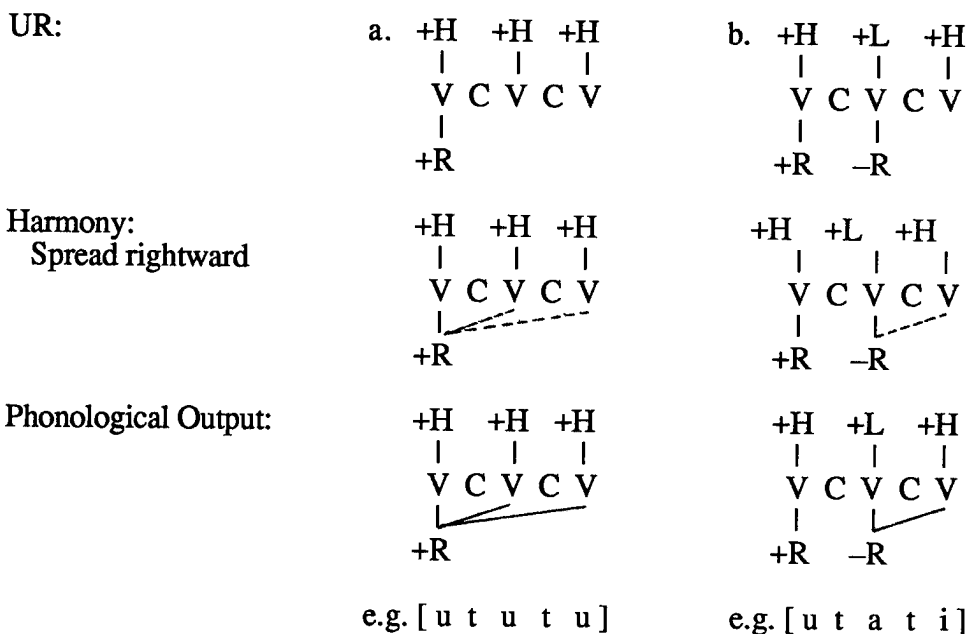
Sundanese has a rule of Nasal Spread, whereby a sequence of vowels and non-supralaryngeal consonants become nasalized when following a nasal consonant. Nasal Spread is subject to certain consonantal blocking effects and also involves an apparent ordering paradox. Before turning to the facts of nasalization in Sundanese, we consider the issue of an adequate account of phonological blocking effects.

We start by asking the question of how blocking effects in phonological spreading (e.g. vowel harmony and nasal harmony) might be accounted for. What is at issue is the fact that in most harmony rules, some classes of segments are amenable to the harmony, while others prevent further spreading.

Consider a simple example. The following example is a schematic version of a vowel harmony system. The facts are not unlike a simplified version of Turkish. (For a discussion of Turkish vowel harmony in the context of possible views of underspecification, see Mester and Itô 1989.) In a vowel harmony system which harmonizes for the feature Round, all vowels in a word would typically agree in rounding: roots such as *iti* and *utu* would be well-formed, but **itu* or **uti* would not be. It is often observed that there are systematic exceptions to such patterns, with forms such as *utati* being well-formed. In such cases, /a/, being [+low], does not contrast for the feature Round and in effect, stops the harmonizing of the feature. The phoneme /a/ is then said to block the harmony or to be opaque to the harmony.

Since the development of autosegmental theory (Goldsmith 1976, Clements 1976), harmony has been widely viewed as spreading of an autosegmental feature (in contrast to previous views where harmony was thought to be feature changing). Following this view, blocking effects are commonly assumed to be due to the presence of a redundant feature specification. This view, which I call the Redundant Specification Approach, is schematized in (1), where I assume a rule which spreads [+round] rightward. (The features High and Low here refer to vowel quality, not to tonal values.)

(1) Redundant Specification Approach R = Round, H = High, L = Low

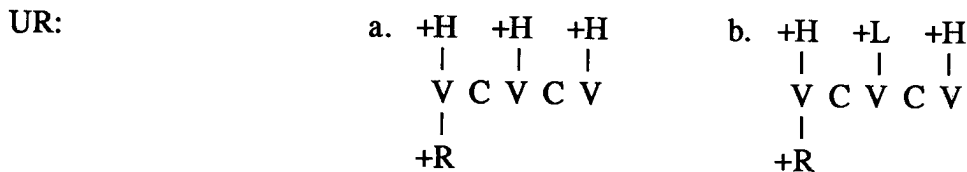


In the underlying representation, [+round] occurs on some segments, some segments are unspecified for the feature Round ([Øround]), and some are redundantly specified as [-round]. I assume that there is some abstract timing structure to the segment (represented here as C's and V's) and that Round occurs on a separate tier from the other vowel quality features. In (1a), the first segment is specified as [+round], but the following two segments are unspecified. The harmony rule spreads [+round] to both of these segments, giving the phonological output as shown. In (1b) the first segment is specified as [+round], the second is redundantly specified as [-round] (since /a/ does not contrast for rounding) and the third segment is unspecified. Here spreading of [+round] is blocked, by the prohibition on crossing of association lines. Assuming the rule is a symmetrical one, [-round] would spread to the final segment, giving the output as shown. This approach accounts for these types of patterns, but results in an unconstrained view of feature specification, since plus, minus, and Ø values are all used in the underlying representation of a single feature, a three-way distinction for a binary feature. Additionally, as will be shown below, this approach is empirically inadequate in accounting for the facts of nasalization spreading in Sundanese.

Consider now the consequences of following an underspecification approach, as outlined in Chapter 1. Recall that I refer to any approach which does not assume specification of redundant feature values as an underspecification approach. Following such an approach, blocking effects in

phonological rules cannot be achieved by the presence of a redundant value, as noted by Archangeli and Pulleyblank (1986). Thus, for example, since /a/ does not contrast for the feature Round, the fact that it blocks Round harmony cannot be due to a redundant [-round] specification. The consequence is that the underlying representation for two forms such as those in (1) would be identical with respect to the representation of the particular feature (in this example Round) as shown in (2):

(2) Underspecification Approach



To maintain a view of underspecification, one in which redundant values do not occur underlyingly, one must appeal to more general structural principles to account for the different outputs in forms such as (1a) and (1b). Archangeli and Pulleyblank (1986) propose configuration constraints to account for precisely such differences. Informally, a configuration constraint is defined as follows: a value α of feature F can/cannot co-occur with a value β of feature G. Such constraints may hold either lexically or both lexically and phrasally. This is not unlike Kiparsky's (1985) principle of Structure Preservation, but it differs in its formalization and makes different predictions about the role of such constraints in certain parts of the grammar. To account for the facts under consideration, a configuration constraint – [+round] cannot co-occur with [+low] – might be in effect. Following this approach, derivations would be as presented in (3) (where a # is used to indicate that such a configuration constraint is in effect.):

(3) Underspecification Approach R = Round, H = High, L= Low

UR:	a. +H +H +H V C V C V +R	b. +H +L +H V C V C V # +R
Harmony: Spread rightward	+H +H +H V C V C V +R	+H +L +H V C V C V # +R
Default Fill-in: ∅ → [-R]	—	+H +L +H V C V C V +R -R -R
Phonological Output:	+H +H +H V C V C V +R	+H +L +H V C V C V +R -R -R
	e.g. [u t u t u]	e.g. [u t a t i]

In (3a), the derivation is similar to (1a). The unspecified segments get their values through spreading, bleeding the Default Fill-in rule which fills in unspecified segments at the end of the derivation. However in the case of (3b), there is no [-round] value present, rather there is a more general principle in effect in the grammar which says that [+round] cannot co-occur with [+low]; let us assume this holds lexically (in addition to underlyingly). Harmony is blocked by the configuration constraint. I follow Archangeli and Pulleyblank (1989a & b) in assuming that such a constraint prevents spreading to or past a segment for which the constraint is applicable. This is accounted for formally by the distinction between free and linked elements. The unspecified segments then receive the redundant value by the Default Fill-in rule, giving the output as shown (effectively the same as in (1b)).

The choice of the Redundant Specification Approach or the Underspecification Approach for accounting for blocking effects has often depended on theoretical assumptions as to whether there is predictable information in the lexicon. Here, I present a different motivation for maintaining underspecification of predictable values. In order to account for the phonetic facts of nasalization in Sundanese, I argue that blocking in the phonology must be due to configuration constraints, not to redundant specifications.

3.2. The data

All previous phonological discussion of nasalization in Sundanese is based on the data and analysis of Robins (1957). Robins proposes an insightful analysis for the long distance effects of spreading of nasalization, supported by kymographic nasal airflow tracings, 17 tokens for a single speaker. Yet the phonetic data are difficult to interpret, as the level of airflow indicated in the tracings is marginal in many of the cases, making it difficult to determine conclusively whether a particular segment is indeed fully nasal or fully oral. Furthermore, the published data set is a small one and there are no minimally contrasting oral forms presented as controls.

At the outset of the present study, it was deemed that a major expansion and reexamination of the Robins data set was warranted, in order to construct a thorough analysis of both the phonetic and phonological facts. To that end, data including most of the forms presented by Robins, with additional relevant cases as well as a systematic collection of minimally contrasting oral forms, were collected for three speakers following the methodology described in Chapter 2. All three speakers were from Bandung, the capital of the Sunda area of West Java, and are speakers of what is described as the prestige dialect of Sundanese. The full wordlist is presented in Appendix A, with markings indicating both the forms which are cited by Robins and those for which kymographic tracings are presented by Robins (the latter being a subset of the former). In the following discussion in §3.3 – 3.5, most attention will be given to one speaker (S-L), whose phonological system is most similar to the patterns described by Robins and who also shows the most systematic behavior across tokens. Reference to a second speaker (S-K) will be made where relevant. (The data for the third speaker suffer from serious leakage between the oral and nasal channels. The data are still interpretable by careful comparison with the control forms, but are not very reliable.)

Unfortunately, there is a slight offset of the baseline in the recording of speaker S-L. This results, in some cases, in what should be zero flow appearing as negative flow. When these data were filtered and rectified, the negative flow became represented as positive flow (i.e. the mirror image of the "negative" flow). This does not pose a significant problem, since the offset of the baseline is quite minimal. Additionally, since raw flow was also recorded, the effects of the false baseline can be factored out. In the presentation of the traces, a dashed line along the baseline has been used to indicate false positive flow resulting in the derived filtered forms. The only problem that resulted from this is that the data are not too accurate for looking at finer details of turning points near the baseline. For such questions the data of the second speaker, S-K, are more reliable.

3.3. Nasalization in Sundanese

3.3.1. The phonological facts of nasalization in Sundanese

As described by Robins (1957) and since discussed widely in the phonological literature, Sundanese has a rule of Nasal Spread: within the word, [+nasal] spreads rightward from a nasal consonant, until blocked by a supralaryngeal consonant. Let us consider first the phonological facts. Examples are given in (4). Here | | is used to indicate phonological output as distinct from

the phonetic output. In these examples, morphological structure not directly relevant to the discussion is not indicated.

(4)		Phonological Output	
a.	/ɲiar/	ɲɪ̃ʔ̃ɑɪ	'seek' (active)
	/ɲaur/	ɲɪ̃ɑ̃ʔ̃ɪ	'say' (active)
	/ɲaian/	ɲɪ̃ɑ̃ʔ̃ɑ̃ɪ	'wet' (active)
	/miasih/	ɪmɪ̃ʔ̃ɑ̃sɪh	'love' (active)
	/niis/	ɪnɪ̃ʔ̃ɪsɪ	'relax in a cool place' (active)
	/nuus/	ɪnʊ̃ʔ̃ʊ̃sɪ	'dry' (active)
	/ɲaatkɪn/	ɲɪ̃ɑ̃ʔ̃ɑ̃tkɪnɪ	'dry' (active)
b.	/mahal/	ɪmɑ̃hɑ̃l	'expensive'
	/mihak/	ɪmɪ̃hɑ̃k	'take sides' (active)
	/ɲaho/	ɲɪ̃ɑ̃hʊ̃l	'know' (active)
	/nuhurkɪn/	ɪnʊ̃hʊ̃rkɪnɪ	'dry' (active)
	/bɪɲhar/	ɪbɪ̃ɲhɑ̃r	'to be rich'
c.	/ɲatur/	ɲɪ̃ɑ̃tʊ̃r	'arrange' (active)
	/ɲudag/	ɲɪ̃ʊ̃dɑ̃g	'pursue' (active)
	/ɲobah/	ɲɪ̃ʊ̃bɑ̃h	'change' (active)
d.	/ɲisər/	ɲɪ̃ʔ̃sɑ̃r	'displace' (active)
e.	/ɲuliat/	ɲɪ̃ʊ̃liɑ̃t	'stretch' (active)
	/ɲaluhuran/	ɲɪ̃ɑ̃lʊ̃hʊ̃rɑ̃n	'be in a high position' (active)
	/marios/	ɪmɑ̃riʊ̃s	'examine' (active)
	/ɲarahitan/	ɲɪ̃ɑ̃rɑ̃hɪtɑ̃n	'wound' (active)
f.	/ɲiwat/	ɲɪ̃ʔ̃wɑ̃t	'elope'
	/ɲawih/	ɲɪ̃ɑ̃wɪh	'sing' (active)
	/mawur/	ɪmɑ̃wʊ̃r	'spread' (active)
	/ɲajak/	ɲɪ̃ɑ̃jɑ̃k	'sift' (active)

In (4a) there are examples of Nasal Spread from a nasal consonant onto a following sequence of vowels; and in (4b) there is spreading through a sequence of vowel-/h/-vowel. But, as shown in (4c & d), Nasal Spread is blocked by supralaryngeal obstruents; as shown in (4e), it is blocked by liquids, both /r/ and /l/; and finally, as shown in (4f), it is blocked by glides, /w, y/. Thus we see that Nasal Spread is indeed blocked by non-nasal supralaryngeal consonants. As shown in (4b), both stem initial and stem medial nasal consonants trigger Nasal Spread.

3.3.2. A phonological analysis of nasalization in Sundanese

Following the assumptions of Lexical Phonology (Kiparsky 1982), Nasal Spread is shown to be a lexical rule by its interaction with morphology; it both precedes and follows infixation. This is exemplified here with the productive process of pluralization – infixation of =ar= or =al=. (The conditions on this regular phonological alternation between /r/ and /l/ are tangential to our discussion.) Examples are presented in (5), where infixed forms, the plurals corresponding to the forms in (4), are presented. In each case, the infix occurs after the initial segment. There is nasalization of the vowel of the infix as well as the vowels of the root. We see here surface violations of the generalization that /r/ and /l/ block Nasal Spread, in that Nasal Spread overapplies: there is nasalization on the vowels following the liquid of the infix.

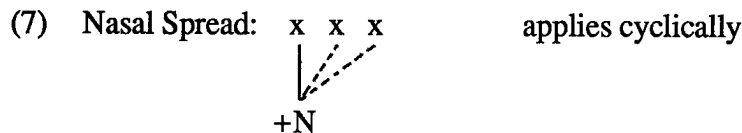
(5)	Singular	Phonological Output		Plural	Phonological Output
a.	/ɲiar/	ɲɪ̃ɪ̃ɑ̃ɪ̃	'seek' (active)	/ɲ=al=iar/	ɲɪ̃ɪ̃ɑ̃ɪ̃ɑ̃ɪ̃
	/ɲaur/	ɲɪ̃ɑ̃ʊ̃ɪ̃	'say' (active)	/ɲ=al=aur/	ɲɪ̃ɑ̃ʊ̃ɪ̃ɑ̃ʊ̃ɪ̃
	/ɲaian/	ɲɪ̃ɑ̃ɪ̃ɑ̃ɪ̃	'wet' (active)	/ɲ=ar=aian/	ɲɪ̃ɑ̃ɪ̃ɑ̃ɪ̃ɑ̃ɪ̃
	/miasih/	ɪ̃mɪ̃ɪ̃sɪ̃hɪ̃	'love' (active)	/m=ar=iasih/	ɪ̃mɪ̃ɪ̃sɪ̃hɪ̃ɑ̃ɪ̃
	/niis/	ɪ̃nɪ̃ɪ̃ɪ̃sɪ̃	'relax in a cool place' (active)	/n=ar=iis/	ɪ̃nɪ̃ɪ̃ɪ̃sɪ̃ɑ̃ɪ̃
	/nuus/	ɪ̃nʊ̃ʊ̃sɪ̃	'dry' (active)	/n=ar=uus/	ɪ̃nɪ̃ɑ̃ʊ̃ʊ̃sɪ̃
	/ɲaatkiɲ/	ɲɪ̃ɑ̃ɪ̃ɑ̃tɪ̃kɪ̃ɲɪ̃	'dry' (active)	/ɲ=ar=atkiɲ/	ɲɪ̃ɑ̃ɪ̃ɑ̃tɪ̃kɪ̃ɑ̃ɪ̃ɲɪ̃
b.	/mahal/	ɪ̃mɑ̃hɑ̃ɪ̃	'expensive'	/m=ar=ahal/	ɪ̃mɪ̃ɑ̃hɑ̃ɪ̃
	/mihak/	ɪ̃mɪ̃hɑ̃kɪ̃	'take sides' (act.)	/m=ar=ihak/	ɪ̃mɪ̃ɪ̃hɑ̃kɪ̃
	/ɲaho/	ɲɪ̃ɑ̃hɔ̃ɪ̃	'know' (active)	/ɲ=ar=aho/	ɲɪ̃ɑ̃hɔ̃ɪ̃ɑ̃hɔ̃ɪ̃
	/nuhurkiɲ/	ɪ̃nʊ̃hʊ̃rɪ̃kɪ̃ɲɪ̃	'dry' (active)	/n=al=uhurkiɲ/	ɪ̃nɪ̃ɑ̃ʊ̃hʊ̃rɪ̃kɪ̃ɑ̃ɪ̃ɲɪ̃

These data are from speaker S-L. The data from speaker S-K are slightly different in that there is not always nasalization after the infix. Since it sometimes occurs, it appears to be the case that whatever rules account for this nasalization might be optional. Those familiar with the data presented by Robins (1957) will note that my data for the phonological output of the plural forms differ slightly in that I do not indicate denasalization of the first vowel following the liquid of the infix. The issue of Denasalization is a complex one. In my data, it does not apply in the systematic fashion reported by Robins. The status of this rule will be discussed in §3.5.

As shown in (6), cyclic application, but not non-cyclic application, accounts for the apparent overapplication of Nasal Spread:

(6)	Non-cyclic Application	Cyclic Application
Input:	/ɲaliar/	Cycle 1: /ɲiar/
Nasal Spread:	ɲãliar	ɲɪ̃ãr
		Cycle 2: ɲ=al=ɪ̃ãr
Nasal Spread:	NA	ɲ=ãl=ɪ̃ãr
Phonological Output:	*ɲãliarɪ	ɲãlɪ̃ãrɪ

Following the assumptions of Lexical Phonology, the fact that Nasal Spread applies cyclically follows from its interaction with morphology (applying in the characteristic fashion of lexical rules). (Of the numerous reanalyses of the Sundanese facts which have appeared in the literature, van der Hulst and Smith (1982) alone propose a cyclic analysis, although not in the framework of Lexical Phonology.) These facts can be accounted for with a rule in which the feature value [+nasal] spreads rightward, cyclically:



What is important for the discussion at this point is the fact that the feature Nasal functions on an independent tier. For the moment, I will not pursue the issue of its hierarchical relationship with other features. This analysis accounts for the apparent ordering paradox. Now we turn to the blocking facts and see that they also follow from the analysis.

In order to consider the effects of consonants on spreading, I present the consonant inventory of Sundanese in (8). I include also the vowel inventory for reference.

(8) Sundanese consonant inventory

p	t	c	k] [-nasal]] [-continuant]
b	d	ɟ	g		
m	n	ɲ	ŋ] [+nasal]] [+continuant]
	l/r	s			
w		j			
			h	(ʔ)	

Sundanese vowel inventory

	front		back
high	i	ɨ	u
mid	e	ə	o
low		a	

Note that Nasal is only distinctive for [-continuant] segments, yet both [+continuant] and [-continuant] segments play a role in Nasal Spread. Also, following current views of the representation of /h/ and glottal stop (e.g. Clements 1985), I assume that /h/ and glottal stop are unspecified for the feature Continuant, since they consist of only laryngeal features. The glottal stop is in parentheses, since, although it occurs in the surface phonology, it is predictable and therefore assumed not to be a phoneme of the language. A striking fact about /r/, a trill, is that it appears to pattern with the [-continuant] consonants. For the moment, I assume that /r/ is phonologically specified as [-continuant] in order to account for this fact. It is possible that the patterning of /r/ with the [-continuant] segments is a phonetic fact, not a phonological one. For the discussion at hand, it is the behavior of /l/, not /r/, that is most relevant. The different behavior of /r/ and /l/ will be pursued below in §3.5.

The following observation must be accounted for in the analysis: as shown above in (4), both [-continuant] and [+continuant] supralaryngeal consonants block Nasal Spread ((4c) and (4d, e, & f) respectively), yet [+nasal] is distinctive for [-continuant] segments and predictable for [+continuant] ones. I argue that the blocking effects of the distinctive segments (those which are [-continuant]) and the predictable ones (those which are [+continuant]) are due to different formal mechanisms.

At the point that Nasal Spread applies, [-continuant] segments are specified for the feature Nasal. This can be accounted for either by early fill-in rules, following the approach taken by Archangeli and Pulleyblank (1986), or by assuming that for those classes of segments where a particular feature is contrastive, both values may be specified underlyingly, following Steriade (1987a). Steriade's approach has an intuitive appeal here, as it is precisely in the class of [-continuant] segments in which Nasal is contrastive that both plus and minus specifications for Nasal are necessary to capture the facts of Nasal Spread. Thus the blocking effects of [-continuant] consonants are accounted for by explicit [-nasal] feature values.

With respect to the [+continuant] consonants, consider the existence of a configuration constraint in the grammar such as the one stated in (9):

- (9) *[nasal]
 |
 [+consonantal]
 [+continuant]

The feature Nasal cannot co-occur with [+consonantal] and [+continuant] (assuming that glides are [+consonantal]). This configuration constraint captures a general cross-linguistic observation (which has very few exceptions) that [+continuant] consonants are not contrastive for the feature Nasal. Note, for example, a similar lexical restriction in Guaraní nasalization, as discussed by Kiparsky (1985, p. 126), where unstressed continuants are unspecified for the feature Nasal.

To account for the fact that [+continuant] consonants also block Nasal Spread, I argue that such a configuration constraint is in effect. The effect of this constraint for Nasal Spread is that it blocks nasalization from spreading to or past [+continuant] consonants. Consider the following derivations to see how this works; # indicates that this constraint is in effect. These derivations do not start with underlying representations in all cases.

(10) Sample Derivations

	a.	b.	c.	d.
Cycle 1:				
Input:	ɲiar +N -N	ɲatur +N -N -N	ɲuliat # +N -N	ɲiwat # +N -N
Nasal Spread	ɲiar ✓ +N +N -N	ɲatur ✓ +N -N -N	ɲuliat ✓ # +N -N	ɲiwat ✓ # +N -N
Cycle 2:				
Infixation:	ɲ=al=iar # V +N +N-N			
Nasal Spread	ɲ=al=iar ✓ +N +N +N-N			
Default fill in:	—	ɲatur ✓ +N -N -N -N	ɲuliat ✓ # +N -N -N -N	ɲiwat ✓ # +N -N -N -N
Phonological Output:	ɲaliar ✓ ✓ +N +N-N	ɲatur ✓ +N -N -N -N	ɲuliat ✓ +N -N -N -N	ɲiwat ✓ +N -N -N -N

The input to the first cycle is as shown. Nasal Spread applies. In (10a), [+nasal] spreads to both vowels, but is blocked from spreading to the /r/ since it is already specified as [-nasal] at this stage in the derivation. In (10b), there is only spreading to the /a/ following the /ɲ/; further spreading is blocked by the /t/, specified as [-nasal]. In (10c) and (10d), again spreading is blocked past the first vowel, but in this case it is not due to a [-nasal] specification, but rather the configuration constraint which prohibits the co-occurrence of Nasal with segments positively specified for both the features Continuant and Consonantal. Note I follow Archangeli and

Pulleyblank (1989a & b) in assuming that such configuration constraints not only prevent linking but also block further spreading if the structure is a linked structure. In (10a) there is infixation on the second cycle. For concreteness, the [+nasal] autosegment is represented here as having been "cloned", that is, split by the infix, but following the Configuration Constraint Approach this might not be necessary. Nasal Spread then reapplies, causing the vowel of the infix to become nasalized in addition to the vowels of the root, already nasalized on the first cycle. Assuming that all vowels are specified for Nasal leaving the phonology, I propose a Default Fill-in rule for the vowels, i.e. those not affected by Nasal Spread. (Phonetic evidence for this rule is presented below in §3.3.3 and §3.5.) After Default Fill-in applies, the phonological output is as shown, where the glides and /l/ are still unspecified for the feature Nasal leaving the phonology.

If on the other hand, we assume that the blocking effects from the [+continuant] consonants are due to redundant values in the phonology (referred to as the Redundant Specification Approach), the phonological outputs would be as shown in (11):

(11) Phonological Output – following the Redundant Specification Approach

a. <i>ɲ a l i a r</i>	b. <i>ɲ a t u r</i>	c. <i>ɲ u l i a t</i>	d. <i>ɲ i w a t</i>
✓ ✓	✓	✓	✓
+N -N+N-N	+N -N -N-N	+N -N-N-N-N	+N -N -N-N

Under this view, the blocking effects of Nasal Spread in all cases would be due to a [-nasal] specification. The blocking of [-continuant] consonants, contrastively specified for the feature Nasal, and [+continuant] consonants, redundantly specified for Nasal, would be formally the same, resulting in the output shown in (11). The crucial difference is that in this case, there are no unspecified segments leaving the phonology; all segments, including glides and /l/, are fully specified for the feature Nasal. How can we distinguish between these two types of approaches? Let us turn now to the phonetic data, to see why the Configuration Constraint Approach and thus Underspecification Theory are to be preferred.

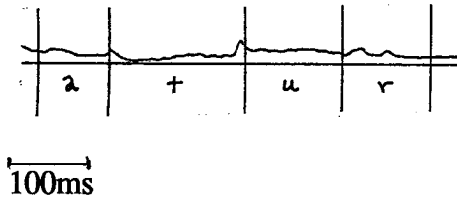
3.3.3. Sundanese: Phonetic data and analysis

In this section representative filtered nasal flow traces, as described in Chapter 2, will be presented as an indirect representation of the phonetic output for the feature Nasal. Presented with the flow traces are schematic representations of the output from the phonetic rules, that is the expected output of rules of target assignment and interpolation. For the time being we assume that targets have inherent duration equal to most of the duration of the segment. This view will be argued for in Chapter 4, at which point we also consider the formal properties of target assignment rules. In these schematic representations, we have abstracted away from the flow traces in the ways described in Chapter 2.

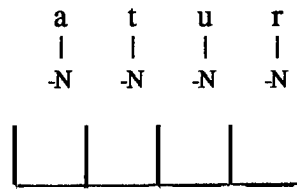
The first example of a nasal flow trace is *laturl* 'arrange' with no nasal segments, shown in (12a).

(12) *laturl* [S-L 1] 'arrange'

a. Observed Nasal Flow



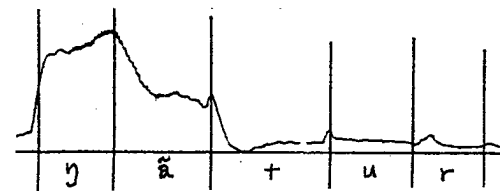
b. Schematic Output of Phonetic Rules (without segmental effects)



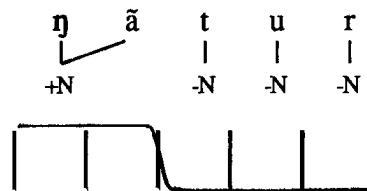
This example exhibits no significant nasal flow; this is as expected as there are no nasal segments in the form. This example sets an effective baseline for the other cases. In the schematized representation, shown in (12b), all the segments have low targets, all being [-nasal] leaving the phonology (under either approach). In (13), there are both nasal and oral segments, exemplified by *lɔ̃aturl*.

(13) *lɔ̃aturl* [S-L 1] 'arrange' (active)

a. Observed Nasal Flow



b. Schematic Output of Phonetic Rules (without segmental effects)



In (13a), there is substantial nasal flow on both *lɔ̃* and the following *lã*, but not on any of the subsequent segments. There is a rapid transition between *lã* and *lɪ*, precisely the kind of transition we would expect to see between a [+nasal] and a [-nasal] segment. As schematized in (13b), under either approach we would expect to see high targets for the first two segments *lɔ̃lã* and low targets for the following segments. There would then be interpolation between the targets. (Here we see that targets with inherent duration more closely approximate the shape of the observed curve than timeless targets would.) The marked difference in level of nasal flow between the nasal and the following vowel is due to the changes in oral constriction as discussed in Chapter 2.

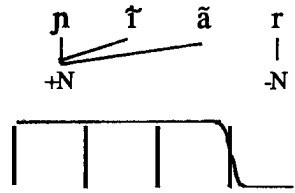
In the next example (14), we see a case of Nasal Spread to a sequence of two vowels, in the form *lɔ̃fãrl*.

(14) *lɲʔãrl* [S-L 1] 'seek' (active)

a. Observed Nasal Flow



b. Schematic Output of Phonetic Rules (without segmental effects)



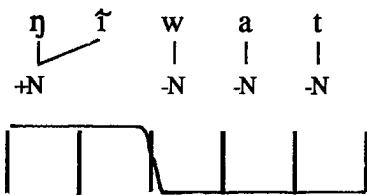
In this case, there is significant flow on the nasal and both of the vowels. In (14b), there are three high targets followed by a low target with a similar transition as seen in (13). The decreasing flow on the /i/ and /a/ is again physical in origin. It is due to the overall rate of airflow through the glottis in relation to the relative size of the oral opening (see House and Stevens 1956), as discussed in Chapter 2. Abstracting away from these physiological effects, we can consider the nasal flow trace in (14a) to correspond to something like (14b).

Let us turn now to the more interesting cases, where the two approaches – the Redundant Specification Approach, and the Configuration Constraint Approach – make different predictions. First consider the case where a [+continuant] consonant, either a glide or /l/, follows a vowel nasalized by Nasal Spread:

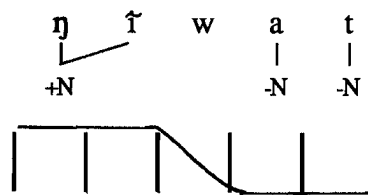
(15) Glides and /l/ following a nasalized vowel

e.g. *lɲʔwatl* 'elope'

a. Redundant Specification Approach



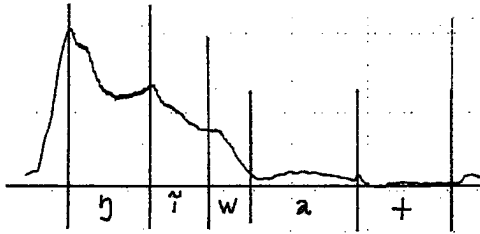
b. Configuration Constraint Approach



The prediction of the Redundant Specification Approach is as shown in (15a). We would expect to see high targets for the first two segments, then low targets for the subsequent segments, including the glide or /l/, since following this approach either would be specified as [-nasal] leaving the phonology. The transition would be expected to look like that seen in *lɲãturl* in (13). On the other hand, following the Configuration Constraint Approach, we would expect the first two segments to have high targets, the final two to have low targets, and the glide or /l/ in the middle to have no target (since it would be unspecified leaving the phonology), as shown in (15b). Here we would expect to see a smooth transition throughout the glide or /l/ from interpolation between the targets on either side of this segment. Looking at actual representative flow traces in (16a, b, & c), *lɲʔwatl*, *lɲãjakl* and *lɲõliatl* respectively, we see a transition throughout the glide and /l/ as predicted

by the Configuration Constraint Approach, quite different from the types of transitions that we saw above in (13a) and (14a). It is clear that this transition is not just an artifact of degree of oral constriction, since we see the same affect for the glides and *ll* in different vowel contexts. Additionally, the expected effect of change in oral constriction for the glide would be greater, not decreasing, nasal flow.

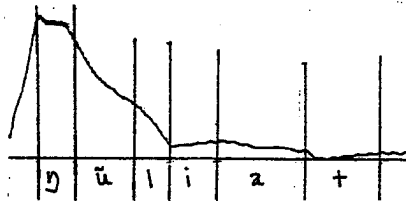
(16) a. *lɲɪʋatɪ* [S-L 1]



b. *lɲãjakɪ* [S-L 4]



c. *lɲɯliatɪ* [S-L 2]



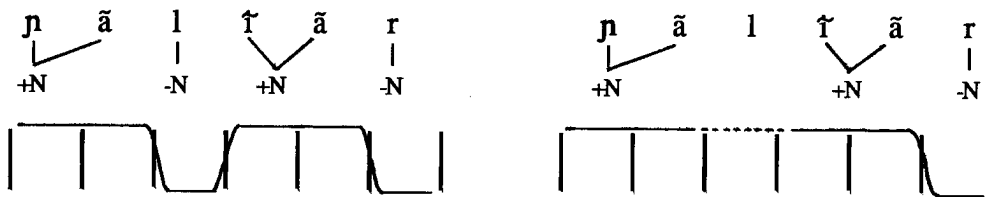
The pattern in these examples looks very much like the transitional formant patterns observed in [h] in the [iɦa] case discussed in Chapter 1, where we observed smooth interpolation throughout the duration of a phonologically unspecified segment.

In these examples, we see phonetic evidence for the Default Fill-in rule for vowels. Were the non-nasal vowels unspecified for the feature Nasal leaving the phonology, we would expect to see a cline-like transition throughout not only the glide or *ll*, but also the following sequence of vowels. This is not the case; rather the vowels are clearly oral. Additional evidence for the Default Fill-in rule is provided below. The fact that a fill-in rule should apply to the vowels (but not to the glides and *ll*) is not surprising, since nasalization of vowels, but not continuant consonants, plays a significant role in the lexical phonology of Sundanese.

The most interesting case is that involving an infixed *ll* (from the plural infix). Again the two approaches make different predictions, as shown in (17).

(17) Infixed *ll* |*n=ãl=ʔãr*l 'seek' (active, plural)

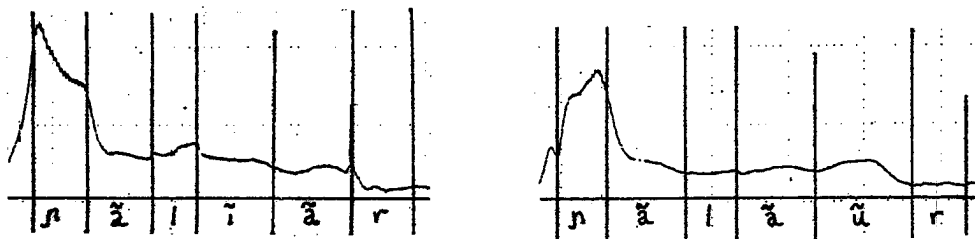
a. Redundant Specification Approach b. Configuration Constraint Approach



Following the Redundant Specification Approach, as shown in (17a), high targets would be expected for the first two segments, a low target for the *ll* (since under this view, it would be specified as [-nasal] leaving the phonology) and high targets for the following two vowels. Thus there should be a large dip in the flow trace for the *ll*. Under the Configuration Constraint Approach (shown in (17b)), the first two segments would have high targets, the following two vowels would also have high targets, but the intervening *ll* would have no target (being unspecified leaving the phonology). In this case, we would expect interpolation straight through, giving the impression that *ll* has a high target, when in fact it has no target. Looking at representative nasal flow traces in (18) |*n=ãl=ʔãr*l and |*n=ãl=ãũr*l, we observe nasalization straight through, precisely as predicted by the Configuration Constraint Approach.

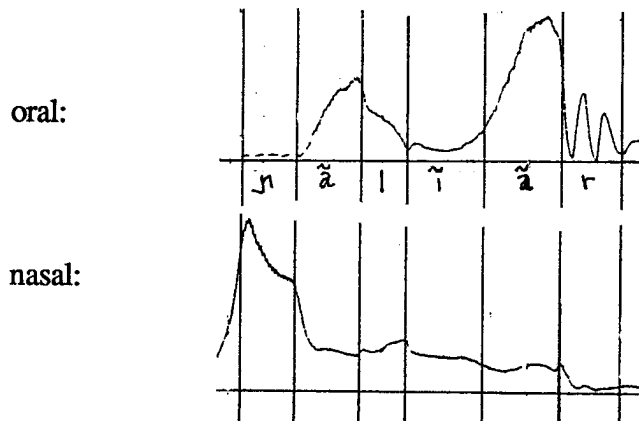
(18) a. |*n=ãl=ʔãr*l [S-L 3]

b. |*n=ãl=ãũr*l [S-L 5]



This pattern is very much like the [aha] case for [h] discussed in Chapter 1, where we observed no change in the [a]-like formant structure during the duration of the [h]. It might be hypothesized that the nasal flow observed during the infixed *ll* is due to the change in oral flow for the consonant. This issue can be resolved by looking at both nasal and oral flow, presented in (19).

(19) Nasal and oral flow compared for |ŋ=ãl=ɾãr| [S-L 3]



The oral flow in *ll* is lower than that observed for *lãl*, but quite comparable to that observed for *lɾl* (actually greater than it). Decreasing oral flow for *ll* would predict increasing nasal flow *ceteris paribus*. We observe a slight increase, but not as much as might be expected. It might be the case that the velum raises slightly for the *lɾl*, due to the overall high tongue position of the *lɾl*.

In both of these final cases (16) and (18), the observed phonetic facts are as predicted by the Configuration Constraint Approach and cannot be accounted for in an obvious way by the Redundant Specification Approach. Following the Configuration Constraint Approach, these segments are unspecified for the feature Nasal leaving the phonology; we would predict, therefore, that they would not get phonetic targets, but rather quantitative levels of nasalization assigned through interpolation. In contrast, under the Redundant Specification Approach, these segments would be [-nasal] phonologically in order to block Nasal Spread. A priori, these segments would be expected to be mapped as low targets, but this is not the observed phonetic output. To account for the phonetics, either the low targets would have to be delinked, but only in specific cases; or somehow the [-nasal] specification would be changed to [+nasal] by the phonetics or a late phonological rule. Any such solution would be an undesirable result, if we want to maintain the idea of a systematic mapping from phonology to phonetics.

In conclusion, we have seen that phonologically [+continuant] consonants in Sundanese block Nasal Spread, but phonetically glides and *ll* are transparent to nasalization. Making the assumptions that first, phonological blocking effects must be accounted for by a structural constraint, such as a configuration constraint, rather than by redundant feature specification, and that second, there is not full specification leaving the phonology, we achieve a principled account of why the glides and *ll* are opaque in the phonology, but transparent in the phonetics.

In this section, the basics of an analysis of both the phonology and phonetics of nasalization in Sundanese were proposed. This analysis offers a simple account of the facts and lends support to the idea that phonology and morphology are interleaved, since it is this assumption that allows us to account for the surface violations of the generalization that liquids block Nasal Spread. In this section, many details of the analysis were left aside; we turn to those details in the next section.

3.4. The phonetics of phonologically transparent segments

In the preceding section, both phonological and phonetic accounts of Nasal Spread in Sundanese were presented. We focused on the phonetic properties of the phonological blockers (although the issue of the different phonetic behavior of /r/ and /l/ was left aside). The phonetic properties of the phonologically transparent segments were not discussed. This is the first question we turn to in this section. We then compare the behavior of /r/ and /l/ in the following section.

There are basically three patterns where long distance effects of Nasal Spread are observed in Sundanese: NVV, NVʃV (possibly a subset of the NVV case, since as discussed below, |ʃ| is predictable in Sundanese) and NVhV. We consider the phonetic realization of each of these patterns in turn, considering first the NVV and NVʃV patterns. The relevant forms are those from (4a) above. These are repeated here as (20), with the corresponding root patterns. (The root patterns for many of the forms cited above start with non-nasals and therefore do not result in Nasal Spread. In the corresponding active forms, if the initial consonant is a voiceless obstruent, it is replaced by the corresponding homorganic nasal, which then triggers Nasal Spread.)

(20) root	phonetic realization	active form	phonetic r.
a. VV			
/siar/	[siʃar] 'seek'	/ɲiar/	[ɲiʃ̃ār]
/saur/	[saʷur] 'say'	/ɲaur/	[ɲāʷ̃ur]
/cai+an/	[caɭian] 'wet'	/ɲaian/	[ɲāɭ̃iʃ̃ān]
b. VʃV			
/pi+asih/	[piʃasih] 'love'	/mi+asih/	[miʃ̃āsih]
/tiis/	[tiʃis] 'relax in a cool place'	/niis/	[niʃ̃iʃ̃s]
/tuus/	[tuʃis] 'dry'	/nuus/	[nuʃ̃iʃ̃s]
/saat/	[saʃat] 'dry'	/ɲaatki-n/	[ɲāʃ̃ātki-n]

Sundanese is very tolerant of vowel-vowel sequences and there are two basic patterns of phonetic realization of these sequences. As shown in (20a), sequences of unlike vowels generally surface with a brief transitional glide between them. The quality of the glide is predictable from the quality of the surrounding vowels. As shown in (20b), patterns with two like vowels, or at certain morphological boundaries, surface with a glottal stop. These surface patterns affect the phonetic realization of nasalization.

3.4.1. The behavior of glides

The glide-like transitions in the unlike VV case are interesting, as their quality is quite clear. One of my consultants was very aware of this pattern of transitions. If it is the case that these glides are inserted by the phonology, it is necessary to account for the fact that underlying glides, but not inserted glides, block Nasal Spread. We observe near minimal pairs such as the following. (I use ̃ to indicate transitional flow in the phonetic realization.)

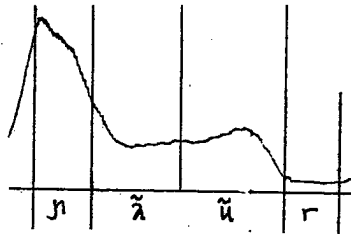
(21) Transitional glides

Underlying glides

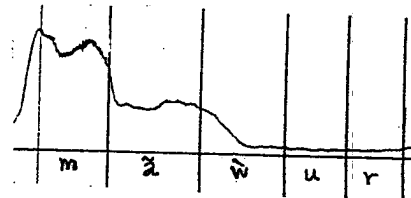
Phonetic R.		Phonetic R.		
/ɲaur/	[ɲã ^w ur]	'say' (active)	/mawur/ [mã ^w ur]	'spread' (act.)
/ɲiar/	[ɲi ^ʔ ãr]	'seek' (active)	/ɲiwat/ [ɲi ^ʔ wat]	'elope'
/ɲaian/	[ɲã ^ʔ i ^ʔ ãn]	'wet' (active)	/ɲajak/ [ɲã ^ʔ jak]	'sift' (active)

The physical realization of this difference is exemplified in the following flow traces of /ɲaur/ and /mawur/:

(22) a. /ɲaur/ [ɲã^wur] [S-L 2]



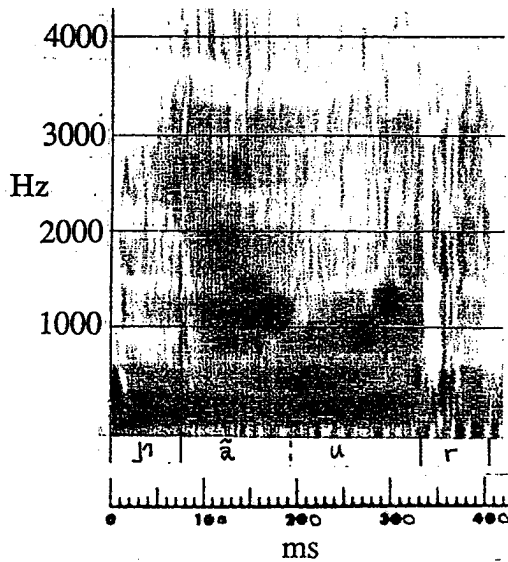
b. /mawur/ [mã^wur] [S-L 1]



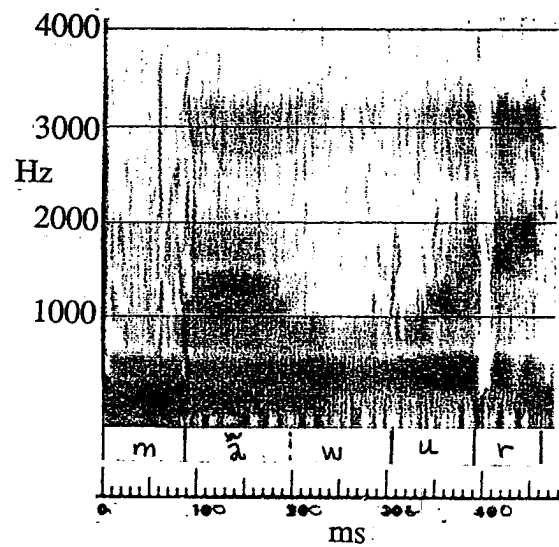
One possible phonological account would be that Glide Insertion is a post-lexical rule, applying after Nasal Spread. Another possible phonological account would be to assume that inserted glides are [-consonantal], whereas the underlying glides are [+consonantal] (as assumed above). Since the inserted glides would be [-consonantal], they would not be expected to function as blockers, since the proposed Configuration Constraint would not apply to them. Yet it is not clear that these transitional glides are phonological at all. Rather, it seems to be the case that these inserted glides in Sundanese are a result of the phonetic formant transitions between the unlike vowels. Compare the spectrograms shown in (23):

(23) Spectrograms of [nã^wur] [S-L 2] and [mã^wur] [S-L 1]

a. [nã^wur]



b. [mã^wur]



These are wide band spectrograms, with a frequency range from 0 Hz to 4000 Hz displayed along the vertical axis and time in ms along the horizontal axis. In the case of [nã^wur], at about 200ms, there is a formant transition from [a] to [u], but only very slight weakening of the formant structure. The loss of higher formant structure is due to the [u] itself. In contrast, in case of [mã^wur], we see a definite weakening of the formant structure and a prolonged transition, from 210ms to 320ms, characteristic of the realization of a glide.

If these transitional glides are really only phonetic transitions, we would expect the timing of the sequence V^wV to be shorter than that of the sequence VwV. The timing facts, although not overwhelmingly conclusive, are compatible with the view that these glides are actually phonetic transitions. (For stronger evidence, many more tokens would be needed and appropriate statistics should be used to show that the difference is a significant one.)

(24) Timing of the vowel-glide-vowel sequence in [nã^wur] and [mã^wur] in ms, from the release of the initial nasal consonant to the contact for the final [r].

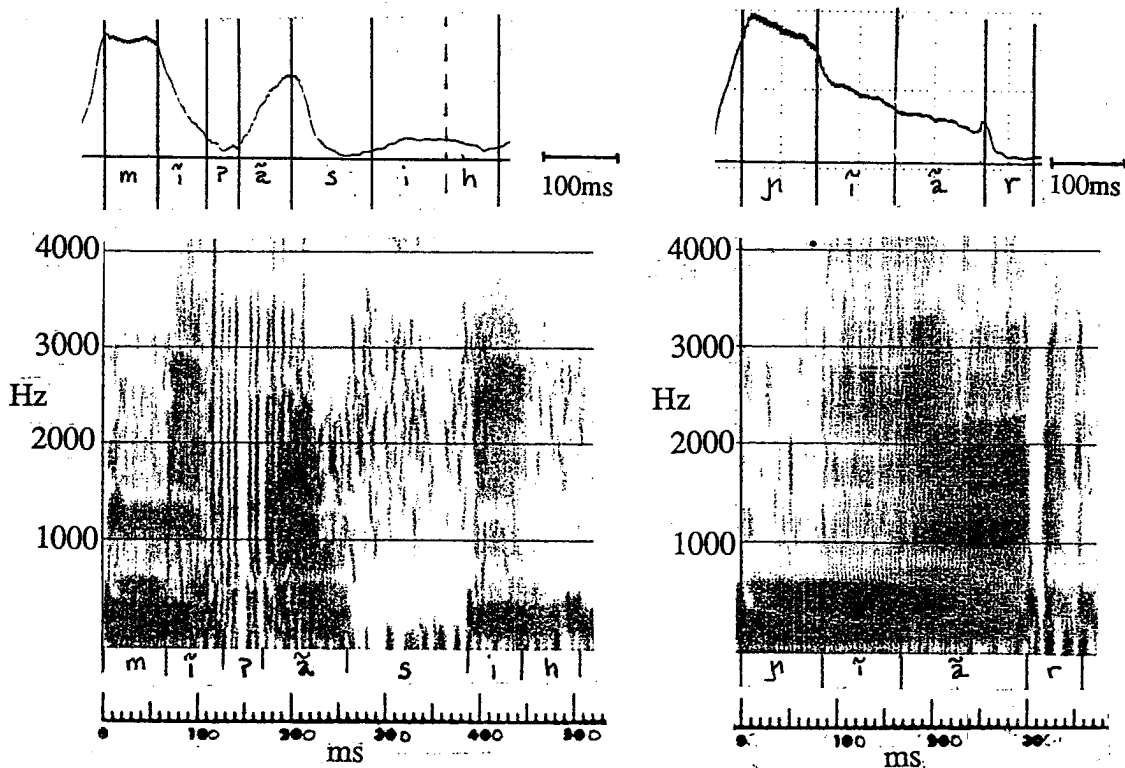
	Token#	1	2	3	4	5	Average
[nã ^w ur]		290	240	200	230	260	244
[mã ^w ur]		320	360	240	310	260	278

If these transitional glides are indeed just phonetic transitions, then their transparency with respect to the phonological rule of Nasal Spread is exactly what we would expect, since they have no status in the phonology.

3.4.2. The behavior of glottal stop

The status of glottal stop, in some ways, parallels that of the transitional glides, as the glottal stop also breaks up vowel-vowel sequences. But its status as a phonological entity is less ambiguous. As noted above, glottal stops occur between like vowels, but also at certain morphological boundaries. We thus observe near minimal pairs such as /mi+asih/ [mĩʔāsih] 'love' (active) and /ɲiar/ [ɲĩʔār] 'seek' (active), as exemplified in the flow traces and corresponding spectrograms shown in (25).

(25) /mi+asih/ [mĩʔāsih] [S-L 4] and /ɲiar/ [ɲĩʔār] [S-L 2]



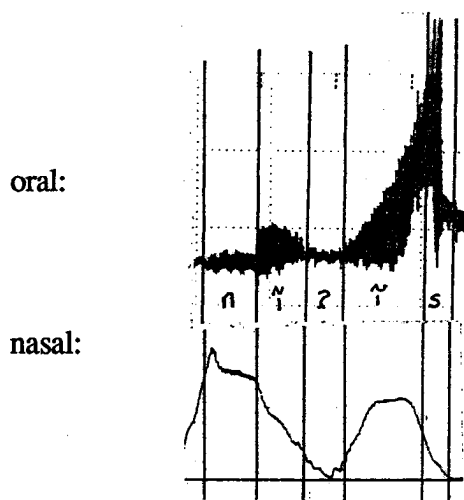
In the spectrograms, we clearly observe the glottal stop in [mĩʔāsih], with characteristic glottalization of both the preceding and following vowels. In the flow trace, we observe a rapid decrease in nasal flow, expected for the glottal stop; since there is a complete stoppage of air at the glottis, no airflow is expected, either oral or nasal. In comparison, there is no change in the vocalic structure or nasal flow in the case of [ɲĩʔār]. This difference can be accounted for simply by observing that there is a morpheme boundary in the former, but not the latter, case. It would be highly undesirable to assume that the phonetics was sensitive to morphological boundaries. It is therefore concluded that the Glottal Stop Insertion must be a phonological process, at least for those cases involving morphological boundaries. (It is not necessarily the case that all glottal stops are inserted by the same rule. It might be the case that the glottal stops inserted between two like vowels have a different status. But, in the absence of any evidence to the contrary, the simplest analysis would be one in which the status of all glottal stops was the same.) Since glottal stop

occurs word-internally, the simplest assumption would be that it is the result of a cyclic rule of glottal stop insertion, although this need not necessarily be the case.

There are two general approaches one might take in order to account for the fact that glottal stop is transparent to Nasal Spread. One might propose an ordering argument: Glottal stops are inserted after Nasal Spread, thus Glottal Stop Insertion would have to be a post lexical rule (a tenable assumption if word internal glottal stops are due to more general junctural effects which require an independent solution). The other approach is to propose a structural account of why glottal stop does not block Nasal Spread. Such an account follows from current views of the appropriate phonological representation of glottal stop (see Clements 1985, Sagey 1986, Steriade 1987b). It is assumed that glottal stop consists of only laryngeal specifications, that it has no supralaryngeal specification. Assuming that the feature Nasal attaches at the Supralaryngeal node (an assumption that will be discussed in §3.4.4), the fact that glottal stop is transparent follows directly, since there is no docking site. This latter explanation presents itself whether Glottal Stop Insertion is a lexical or a post-lexical rule.

Phonologically glottal stop is transparent to Nasal Spread, yet phonetically, using airflow as a measure, it appears to be oral. Although nasalization clearly spreads to the vowel following the glottal stop, the glottal stop itself is oral. This was seen in the flow trace for [mʰfāsih] in (25). Superficially this is an odd result. But recall, as noted in Chapter 2, glottal stop is a case where nasal airflow is not necessarily an indication of velum position. The lack of nasal airflow for glottal stop is due to the behavior of the glottis. During a glottal stop, there is complete closure of the glottis, thus all airflow is cut off. There is neither nasal nor oral airflow. The absence of nasal airflow tells us nothing about velum position. Note there is no reason to assume that the velum changes its position during the glottal stop (i.e. that it raises and lowers). The fact that there is no airflow at all, oral or nasal, during the glottal stop can be seen by comparing the oral and nasal flow traces of glottal stop, as exemplified in /niis/ 'relax in a cool place' (active) in (26).

(26) /niis/ [S-L 2] (raw) oral and (filtered) nasal flow



The raw oral flow has been represented here, as this is more illustrative than the filtered oral flow due to the offset in baseline noted above. We see that during the duration of the glottal stop

there is neither oral nor nasal flow, thus the absence of nasal flow tells us nothing conclusive about the velum position.

The case of glottal stop is one of the few cases where nasal airflow is only an indirect measure of velum position. The position taken here, as widely assumed in the literature, is that velum position, or more precisely velo-pharyngeal opening, is the primary physical indicator of the feature Nasal. This is a case in which we need to abstract away from the observed flow data in discussing the physical output of the feature Nasal. Following the view that velum position is primary, a glottal stop in such a case is phonetically nasal, since we assume the velum remains lowered, yet perceptually, there would be no cue of this nasalization (except perhaps cues during the transitions into and out of the glottal stop). Phonetically the behavior of glottal stop is similar to that of /l/, whereas their phonological behavior is quite different.

Note that glottalization at the end of the first vowel and beginning of the second vowel has the effect of lowering nasal airflow, due to the overall lowering of airflow through the glottis. Glottalization in such forms accounts for the cline-like quality of the airflow on the vowels which are argued to be [+nasal] and therefore would otherwise be expected to have a significant amount of airflow for most of their duration.

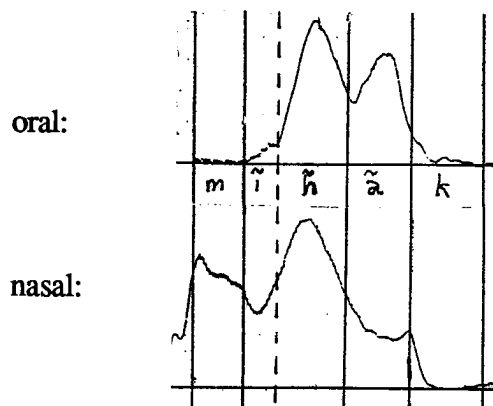
3.4.3. The behavior of /h/

Another interesting class of forms are those involving /h/. Unlike the transitional glides and glottal stop, there is no question about the underlying status of /h/; it is clearly a phoneme of Sundanese. The relevant forms are repeated from (4b) as (27):

(27)	VhV	Phonetic realization	
	/mahal/	[mãhãl̥]	'expensive'
	/mihak/	[mɪhãk]	'take sides' (active)
	/naho/	[nãhõŋ]	'know' (active)
	/nuhurki:n/	[nũhũrkɪ:n]	'dry' (active)

As observed above, /h/, like glottal stop, is transparent to Nasal Spread. It is also phonetically amenable to nasalization. The phonetic nasalization can be seen clearly in the following flow trace, where both oral and nasal flow are presented.

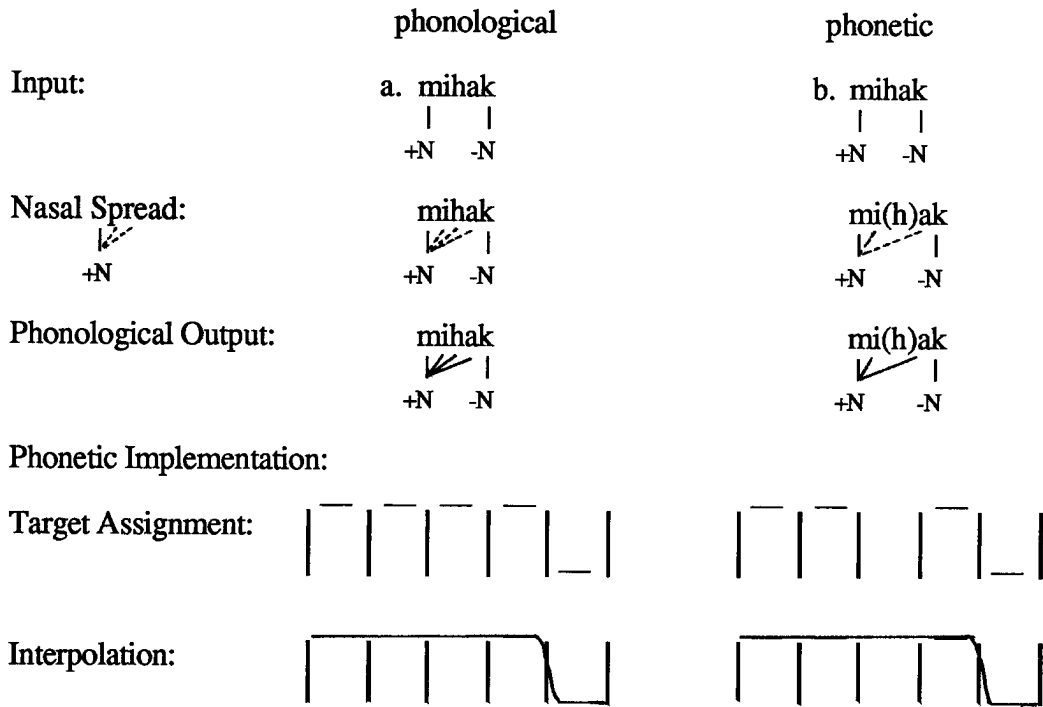
(28) /mihak/ [mʰiãk] [S-L 4]



Looking at just the nasal flow trace, it appears that /h/ has a higher rate of nasal airflow than any other segment. This is a consequence of the fact that the overall rate of flow through the glottis is much greater during /h/ than the neighboring segments. This can be seen by comparing the oral and nasal flow traces. The rapid increase in nasal flow is accounted for by the increase in overall flow and is not due to a change in velum position. In this environment, [h] is clearly nasalized. This conclusion, for which the evidence is very robust in my data, disagrees with Anderson's (1972) conclusion that intervocalic /h/ in Sundanese is not nasalized. His conclusion is based on two kymographic tracings from Robins (1957) of the forms /pahokɨn/ and /kumaha/, where there is negligible flow, both oral and nasal, for the particular token. The observed difference between these forms and the form /bɨŋhar/, which can more clearly be seen to have nasal airflow in the kymographic tracing, may well be due to the [h] being voiced in the first two cases and voiceless in the latter, since voiced /h/ would be expected to have lower overall airflow. Conrax, Howard and Ikranagara (1974) also argue against Anderson's conclusion.

The question that needs to be addressed is how /h/ gets nasalized. Is this a result of its being phonologically specified as [+nasal]? Not necessarily: it might well be the case that /h/ in this environment is unspecified for the feature Nasal leaving the phonology and is phonetically realized as nasalized due to interpolation. The nasalization of [h] in this case would parallel the case of [h] receiving its [a]-like formants from the neighboring [a]'s in the sequence [aha], discussed in Chapter 1. Its phonetic implementation would be like the phonetic implementation of /l/. Two possible derivations of the nasalization of /h/ are schematized in (29):

(29) Two possible derivations of [h̃]

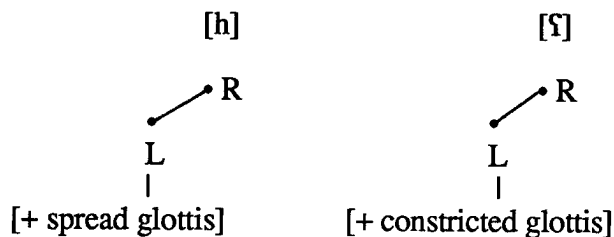


In this case, observing phonetic output alone will not allow us decide between these two different approaches, since in either case, the [h] would be expected to be fully nasalized. Since no other contexts suitable for distinguishing these two representations obtain in the language, we have to base our decision on other criteria.

3.4.4. Implications for the feature geometry

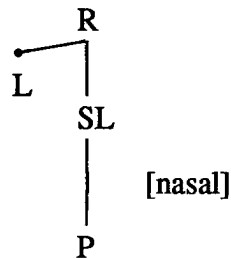
What is at issue in saying that /h/ is or is not [+nasal] leaving the phonology? Phonologically, /h/ and /ʕ/ pattern alike as transparent to Nasal Spread. The fact that they pattern together is not coincidental. It is assumed that they pattern alike for structural reasons: they are both laryngeal specifications for which supralaryngeal articulation is not relevant. Under current views of the hierarchical arrangements of features (Clements 1985, Sagey 1986, Steriade 1987b), [h] and [ʕ] are assumed to have no supralaryngeal specification as represented in (30) (where R = root node and L = laryngeal node).

(30) The representation of [h] and [ʕ]



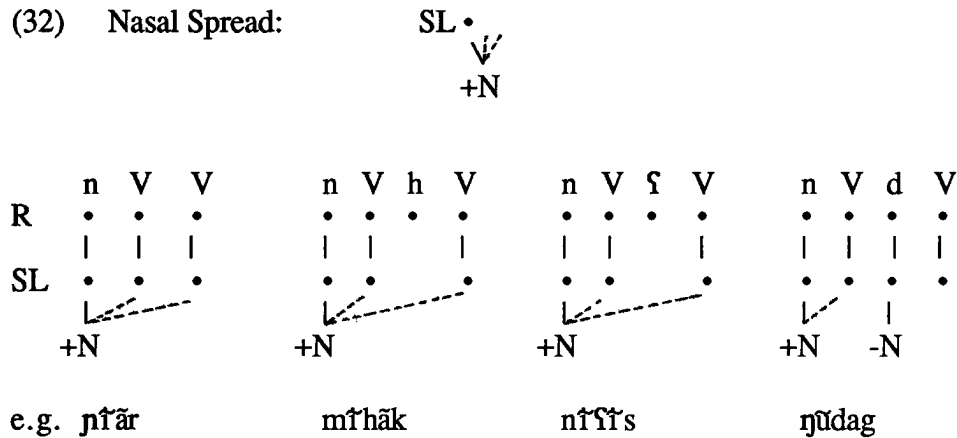
It is often assumed that the feature Nasal hangs off of the supralaryngeal node, as represented in (31) (either alone or with certain manner features). (Under some views, Nasal is linked only indirectly to the supralaryngeal node through the intermediate presence of a soft palate node (as assumed by Sagey 1986, Trigo 1988). To my knowledge, there is no strong evidence for the presence of this intermediate node, but its possible presence is tangential to the issues being discussed here.) Here SL = Supralaryngeal node, P = Place node.

(31) The location of the feature Nasal in the feature geometry



Under this view, the fact that [h] and [ʕ] are transparent to Nasal Spread follows automatically from the fact that they have no supralaryngeal specification. They thus have no nasal specification. The application of Nasal Spread within the feature geometry is schematized in (32):

(32) Nasal Spread:



The configuration presented in (31) makes two predictions: (1) In Sundanese, neither [h] nor [ʕ] is phonologically specified as [+nasal], therefore they should not play a role in the phonological propagation of Nasal Spread. For example, [h] should not be able to spread [+nasal] on subsequent cycles. This prediction is difficult to test, since in a form such as NVh + V, even if the following vowel is nasalized, it could be due to spreading from the preceding vowel, with [h] remaining transparent, rather than spreading from the [h] itself. (2) Since it is widely assumed that the feature geometry should be universal, this view would mean that cross-linguistically [h] and [ʕ] would not be expected to be specified for the feature Nasal. In other words, languages would not be expected to exhibit phonological contrasts such as $\begin{bmatrix} \text{h} \\ \text{-nasal} \end{bmatrix}$ and $\begin{bmatrix} \text{h} \\ \text{+nasal} \end{bmatrix}$; and [h] and [ʕ] would not be expected to participate in either the blocking or the propagation of the feature Nasal. This prediction seems to hold in the vast majority of languages of the world.

There are two possible counter-examples that I know of with respect to nasalization of [h]. One is in Kwangali (Ladefoged personal communication) and the other is in UMBundu, where /h/ and /ɦ/ are claimed to occur underlyingly (Schadeberg 1982). In the latter case, Schadeberg proposes an analysis whereby both continuant consonants and vowels contrast for nasality. He says that this is a very adequate analysis of the facts. Yet this is an uneconomical analysis, since these instances of nasality are closely tied to the final syllable of the stem. Additionally, many distributional facts are missed by assuming that the feature Nasal is a segmental property in these cases. Even if the analysis which assumes that both continuant consonants and vowels contrast for nasality is the most adequate, we have strong incentive to find an analysis which makes UMBundu look less, rather than more, exceptional. It appears to be the case that the feature Nasal may be a lexical property of the last syllable of the stem. Following this approach we can avoid assuming that there is an underlying phonemic contrast between /h/ and /ɦ/ and /l/ and /ɺ/; but it seems likely that these surface contrasts exist, at least for /l/ and /ɺ/. If this is the case, this would then be an example of a language where the configuration constraint proposed above does not apply.

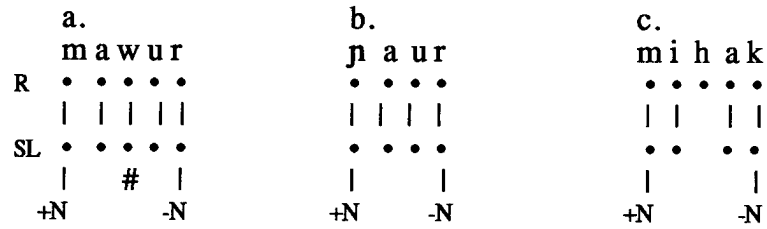
If it is indeed the case that such contrasts exist (either underlyingly or derived), and there is not an adequate alternate analysis (e.g. the feature Nasal is the property of the syllable and results in phonetic nasality of an /h/), it might be argued that only in these cases is there a fill-in rule giving the laryngeals a supralaryngeal node (with a [+nasal] specification). The presence of a structure building rule for such cases is much less undesirable than assuming that /h/ and /ɦ/ are potentially specified for Nasal, thereby losing the account of the very general observation of transparency.

Piggott (1987) has argued that the feature Nasal should be attached to the Root node directly to account for what he terms nasal stability facts. If this view should prove correct (but see Trigo's 1988 argument against this view of nasal stability), the prediction that [h] and [ɦ] are necessarily unspecified for Nasal is lost. Following this view, all laryngeal segments should have a specification for Nasal. Thus, [h, ɦ] would not be expected to be transparent to nasal spreading. Under this view, what is odd or special in Sundanese is that the laryngeals are unspecified for Nasal. Yet this is problematic since vowels and laryngeals do not form an obvious natural class, particularly to the exclusion of glides [y, w]. A way around the undesirable prediction that there is no principled reason that [h] and [ɦ] should remain unspecified for the feature Nasal would be to assume that the feature Continuant was attached at the Supralaryngeal node and that both /h/ and /ɦ/ are unspecified for Continuant. Under this view, the transparency of /h/ and /ɦ/ could still be accounted for, but this would be a less elegant account.

To summarize, I assume that the configuration is as presented in (31) and that the transparency of [h] and [ɦ] is due to the hierarchical configuration of features. This accounts for the fact that [h] and [ɦ] pattern alike phonologically, functioning as transparent to Nasal Spread. It is assumed that, at least in Sundanese, both remain unspecified for the feature Nasal at the output of the phonology. Both can be nasalized phonetically, through interpolation between [+nasal] segments preceding and following. Their phonological and phonetic behavior are parallel. As discussed above, the fact that [h] has such high nasal airflow and the fact that glottal stop has no nasal airflow are due to independent issues of physiological patterns of airflow and not indicative of any significance difference of velum position for these two segments. In (33), sample derivations are presented.

(33) Sample derivations

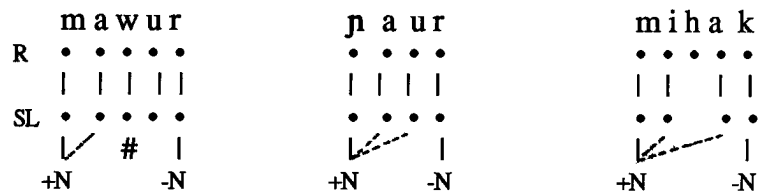
Input:



Nasal Spread:

↙ ↘

+N

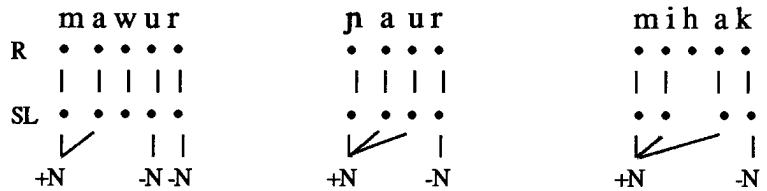


Default Fill-in:

∅N → -N



Phonological Output:

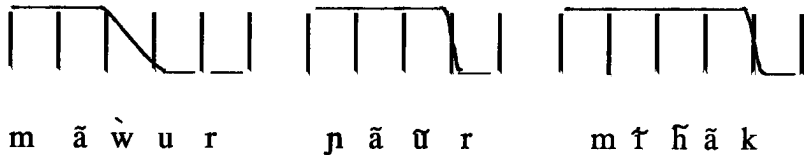


Phonetic Implementation:

Target Assignment:



Interpolation:



The derivations in (33a & b) are similar to those seen above. In (33a), Nasal Spread applies, spreading [+nasal] to the vowel, but further spreading is blocked by the proposed configuration constraint. The Default fill-in rule then applies. In (33b), Nasal Spread applies to both vowels, but is blocked by the [-nasal] specification of the /r/. In (33c), Nasal Spread applies, spreading [+nasal] to both of the vowels. Since spreading is from the Supralaryngeal node, this is achieved

in a strictly local fashion, as it does not "see" the [h]. The feature specifications are translated into targets. There is then interpolation between the targets; as a result [h] is phonetically nasalized. Its phonetic nasalization is parallel to the phonetic nasalization of the infix /l/ discussed above.

3.5. /r/ vs. /l/

It was noted above that phonologically both /r/ and /l/ function as blockers with respect to Nasal Spread; yet phonetically [l] is amenable to nasalization while [r] is not. It was assumed that the difference was due to a difference in phonological specification: /l/ as [+continuant], /r/ as [-continuant]. In this section, we consider the source of this difference and also the status of the process of denasalization discussed by Robins (1957), whereby a vowel immediately following an /r/ or /l/ of the infix is described as being oral.

As shown in §3.3, both /r/ and /l/ block Nasal Spread and they both create surface violations of this generalization when infix. In these cases and only in these cases, there is nasalization of following vowels. Relevant examples from (4) and (5) are repeated in (34), with the addition of some forms of the shape Nl and Nr.

(34)

a. /r/ and /l/ as phonological blockers

i. Nr / Nl

	phono rep	phonetic realization	
	/paŋlai/	[paŋlai]	'a type of plant'
	/paŋliŋ/	[paŋliŋ]	'unrecognizable'
	/aŋrəm/	[aŋrəm]	'to ripen'
	/caŋra/	[caŋra]	'very nice weather'
but cf.	/kana/	[kanā]	'for the purpose'

ii. NVr / NVl

	phono rep	phonetic realization	
	/ŋuliat/	[ŋũliat]	'stretch' (active)
	/ŋaluhuran/	[ŋāluhuran]	'be in a high position' (active)
	/marios/	[mārios]	'examine' (active)
	/ŋarahi-tan/	[ŋārahī-tan]	'wound' (active)

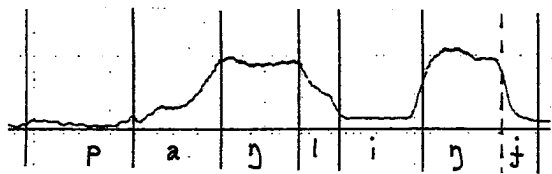
b. surface violations of /r/ and /l/ as blockers

<u>Base forms</u>		<u>Infixed forms</u>	
phono rep	phonetic realization	phono rep	phonetic r.
/ɲiar/	[ɲīār]	/ɲ=al=iar/	[ɲāīār]
/ɲaur/	[ɲāūr]	/ɲ=al=aur/	[ɲāīāūr]
/ɲaian/	[ɲāīān]	/ɲ=ar=aian/	[ɲāīān]

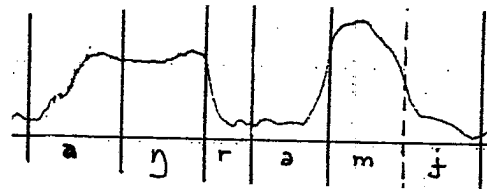
In (34a), we see examples of phonological blocking. In (34a.i.), the [r] or [l] is immediately adjacent to the nasal and the following vowel is oral. In (34a.ii.), the [r] or [l] follows a vowel, which itself follows a nasal; the vowel before the liquid, but not after the liquid, is nasalized. In (34b), we see the surface violations of this observation. These surface violations were argued above to follow from the proposed cyclic analysis. Let us consider the phonetic realization of these phonological patterns. We look first at flow traces for the blocking pattern of (34a), presented in (35):

(35) The phonetic realization of /l/ and /r/ as phonological blockers

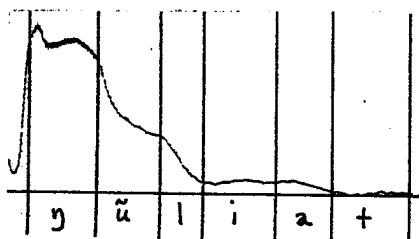
a. [pánliŋ] [S-L 5]



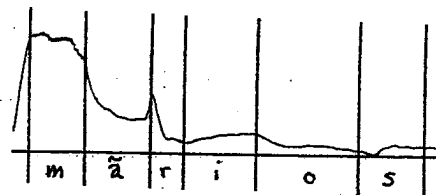
b. [ánrəm] [S-L 1]



c. [ŋt̃liat] [S-L 4]



d. [mārios] [S-L 5]



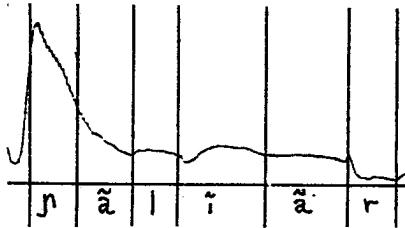
In (35a) and (35c), we see that [l] does indeed block spread of nasalization onto a following vowel, but the [l] itself may be partially nasalized (as discussed in §3.3). It was argued that this was because [l] was actually unspecified for the feature Nasal leaving the phonology. The phonetic pattern for [r] is somewhat different. As seen in (35b) and (35d), we observe a rapid transition at the beginning of the [r], similar to the kind of transition seen in [t] of /ŋatur/ in (13), although the overall duration of the segment is shorter. (The forms in (35a) and (35b) are followed by the [j] of the frame sentence.)

The final vowels in both (35a) and (35b) also provide examples of the typical realization of the transition from a vowel specified as [-nasal] to a following nasal consonant, specified as [+nasal]. Note that the cline-like pattern on /a/ in the first syllable of each of these two examples, marked with an acute accent, is not what we would expect and is quite different from the pattern observed on the vowels in the second syllable in each case. This has to do with the specific sequence of /ar/ when in the same syllable, which results in surprisingly high nasal flow on the vowel. There appears to be anticipatory nasalization in this one particular context, which may be in the process of becoming phonologized. For speaker S-K, there is sometimes even deletion of the /r/ in such cases (but only when following /a/). The /ar/ pattern warrants further investigation.

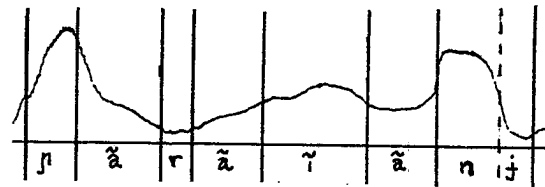
In summary, we observe that both [r] and [l] prevent nasalization of a following vowel; yet [r] itself is oral for most of its duration, while [l] may be partially nasalized. We consider below why this should be the case, but first we compare examples of flow traces for the infix forms as presented in (36):

(36) The phonetic realization of infix /r/ and /l/

a. [nāl̥r̥ār] [S-L 4]



b. [nār̥āf̥ān] [S-L 5]



In (36a), as in (18), we observe nasalization straight through the infix [l]. This was argued to be due to phonetic interpolation of [l], unspecified for the feature Nasal leaving the phonology. In (36b) we see that [r], unlike [l], is not nasalized straight through; rather [r] is oral. Looking back at both the oral and nasal flow in the form /jal̥iar/ in (19), we observe that there is no nasal flow during the /r/ during either the contact or the non-contact portions of the [r]. In Sundanese, [r] appears to have a phonetic low target (in contrast to [l] which was argued to have no target). Note also that the orality of [r] has some effect on the following vowel; this will be discussed below. We observe then that [l] and [r] pattern alike phonologically in that they both block Nasal Spread and lead to the same surface violations of Nasal Spread when infix; but they pattern differently phonetically, in that [r] has a low phonetic target and [l] has no target.

There are two quite different approaches that we might take to account for this difference:

(1) The difference is phonetic: [r] is not aerodynamically amenable to being phonetically nasalized. It does not seem surprising that [r], a trill in Sundanese, should be phonetically oral. It seems quite likely that the aerodynamic requirements of the trill can only be fulfilled if the velum is raised (see Ohala 1971 for similar observations regarding fricatives). The orality of [r] would be ensured through an articulatory constraint. Other such articulatory constraints have been observed. Thus for example, in English, [s] is phonetically [+high], yet this [+high] specification does not appear to play a role in the phonology (see Keating 1988b).

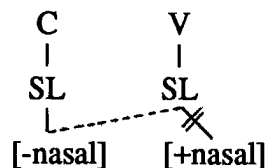
(2) The difference is phonological: /r/, a trill, is specified as [-continuant], since at some points it has full closure; thus it patterns with the other oral [-continuant] consonants. Under this approach it would be a coincidence that /r/ and /l/ appear to pattern alike phonologically. This account would make very different assumptions about the phonological specifications of the feature Continuant for liquids than that made in SPE. In SPE, it was assumed that either /l/ was [-continuant] and /r/, of any type, was [+continuant] or that both were [+continuant]. Sundanese would be quite different, with /l/ being [+continuant] and /r/ being [-continuant]. This is not necessarily a problem, since it seems likely that there are language specific differences in the specification of the feature Continuant based on the types of articulations in particular languages.

The pattern observed in SPE, not surprisingly, fits the facts of English, where /l/, at least when not velarized, patterns as [-continuant] and /r/, a glide-like segment with no contact, is [+continuant]; indeed Kahn (1976) shows that English /r/ is [-consonantal].

What kind of evidence would be necessary to decide between these two approaches? Two possible sources come to mind: (1) independent examples of /r/ patterning with the [-continuant] segments; (2) evidence of /r/ having a phonological [-nasal] specification, expected only if /r/ were indeed a [-continuant] segment (since if it were [+continuant], the proposed configuration constraint would prevent any specification for the feature Nasal). I do not have independent evidence of /r/ patterning with the [-continuant] consonants, but the facts of Denasalization, as described by Robins, are suggestive with respect to /r/ being phonologically [-nasal]. We turn now to the issue of Denasalization.

Robins observes that in the infix forms, the vowels of the first and third syllable, but not the second are nasalized, schematically $N=\check{V}r=V\check{V}$. He observes that ". . . in these forms the second syllable, consisting of the r or l of the infix and the first vowel of the root is not nasalized." (Robins 1957, p. 93). Following Robins' description of Denasalization, most phonological analyses assume a rule of Denasalization, whereby a nasalized vowel following the infix /r/ or /l/ is denasalized. In our terms, this would be the spreading of the orality of the preceding [-nasal] specification to a following nasal vowel:

(37) Denasalization (bounded by the syllable)

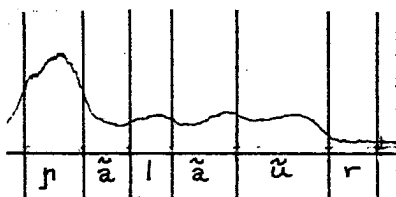


The relevant forms from (5) are repeated here in (38), with the forms as cited by Robins, if he cites the particular form. The data are grouped by type of segment which occurs between the vowels as well as whether the plural infix is of the form =ar= or =al=.

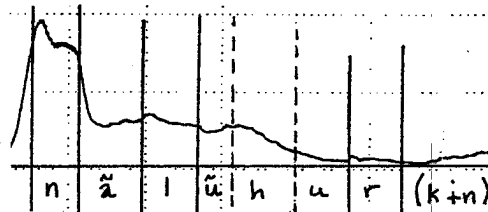
(38)	Singular	Phonetic Output	Plural	Phonetic Output my data	Phonetic Output Robins' data
a.	VV				
/l/ pl	/ɲiar/	[ɲɪ̃ɑ̃r]	/ɲ=al=iar/	[ɲɑ̃ɪ̃ɑ̃r]	
	/ɲaur/	[ɲɑ̃ũr]	/ɲ=al=aur/	[ɲɑ̃ɪ̃ɑ̃r]	[ɲɑ̃ɪ̃ɑ̃r]
/r/ pl	/ɲaian/	[ɲɑ̃ɪ̃ɑ̃n]	/ɲ=ar=aian/	[ɲɑ̃rɑ̃ɪ̃ɑ̃n]	[ɲɑ̃rɑ̃ɪ̃ɑ̃n]
b.	VɣV				
/l/ pl	-				
/r/ pl	/miasih/	[mɪ̃ɑ̃sɪ̃h]	/m=ar=iasih/	[mɑ̃rɪ̃ɑ̃sɪ̃h]	
	/niis/	[nɪ̃ɪ̃s]	/n=ar=iis/	[nɑ̃rɪ̃ɪ̃s]	[nɑ̃rɪ̃ɪ̃s]
	/nuus/	[nũ̃ũ̃s]	/n=ar=uus/	[nɑ̃rũ̃ũ̃s]	
	/ɲaatkɪn/	[ɲɑ̃ɪ̃ɑ̃tkɪn]	/ɲ=ar=aatkɪn/	[ɲɑ̃rɑ̃ɪ̃ɑ̃tkɪn]	
c.	VhV				
/l/ pl	/nuhurkɪn/	[nũ̃hũ̃rkɪn]	/n=al=uhurkɪn/	[nɑ̃ɪ̃hũ̃rkɪn]	
/r/ pl	/mahal/	[mɑ̃hɑ̃l]	/m=ar=ahal/	[mɑ̃rɑ̃hɑ̃l]	[mɑ̃rɑ̃hɑ̃l]
	/mihak/	[mɪ̃hɪ̃ɑ̃k]	/m=ar=ihak/	[mɑ̃rɪ̃hɪ̃ɑ̃k]	
	/ɲaho/	[ɲɑ̃hõ]	/ɲ=ar=aho/	[ɲɑ̃rɑ̃hõ]	[ɲɑ̃rɑ̃hõ]

The application of the putative process of Denasalization in my data is not as straightforward as the description given by Robins. Very generally, it seems to apply in the case of infixes /r/ but not infixes /l/. Consider first the forms with infixes /l/. As seen in the flow trace of /ɲ=al=iar/ in (36a), the /l/ is fully nasalized and there is no apparent denasalization of the following vowel. This is the case as well for the form /ɲ=al=aur/, exemplified in (18) above and presented in (39a).

(39) a. [ɲɑ̃ɪ̃ɑ̃r] [S-L 3]



b. [nɑ̃ɪ̃hũ̃rkɪn] [S-L 1]



The only other example in the corpus with an infixes /l/, /n=al=uhurkɪn/, is rather problematic as in only one of the five tokens did Nasal Spread result in long distance effects. But, in this one token, shown in (39), the [l] is fully nasalized and there is no indication of denasalization of the following vowel (although the second /u/ is only marginally nasalized). (At first blush, it appears that Nasal Spread might be optional, but it is odd because this optionality only occurs with the infixes forms. It is more likely that Cloning (the copying of the [+nasal] autosegment due to the insertion of the infix) is optional, that the insertion of the infix may prevent

further spreading in some cases. Additional support for the view that Cloning is optional comes from speaker S-K, for whom Nasal Spread in the simple cases is very systematic, but in the infix cases is much less regular than for speaker S-L.)

There are no examples of the form N=al=VɿV in my corpus (such as /n=al=iɿir/ 'to skewer' (active, plural)). This is due to the fact that at the outset of the study, when the word list was constructed, I did not anticipate a difference in the behavior of /r/ and /l/, as no such difference was previously discussed in the literature. It would be interesting to compare such forms, but it is not anticipated that their behavior would be much different from the other /l/ infix forms.

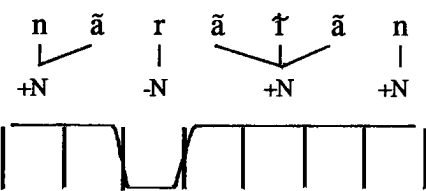
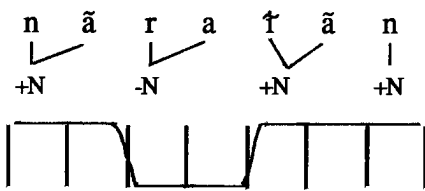
It is the case that for speaker S-L (as well as the two other speakers recorded in this study), there is no denasalization of a vowel after [l]. This is not in the least surprising; since the [l] itself is not oral, it would, therefore, not be expected to impose orality, (whether phonetically or phonologically) on a following vowel. Thus where the difference lies between my data and Robins' is in [l]'s amenability to nasalization. This might be something that varies between dialects or it might be due to something particular about the nature of the articulation of [l] for particular speakers (e.g. some speakers produce [l]'s which are [-continuant], whereas my particular speakers produce [+continuant] [l]'s). It is interesting to note, however, that the one kymographic tracing of a form with an infix /l/, /n=al=aur/, that Robins presents is quite ambiguous. There does appear to be a slight perturbation of nasal flow trace during both the /l/ and the following /a/, leading one to question how systematically denasalization after an infix /l/ occurred even for Robins' speakers.

The facts of infix /r/ are quite different; as we shall see, much more similar to the situation described by Robins. We have already seen an example of a flow trace for an infix /r/ with a following VV sequence, in (36b). We observed that the orality of the [r] had some impact on the following vowel, but it is not clear whether the effects are significant enough to be judged the result of a phonological rule of Denasalization, rather than a more gradient consequence of phonetic implementation. The best way to answer this question is by comparing such forms with ones in which there is a following VɿV or VhV sequence, because these unspecified laryngeals offer a longer span over which to consider the putative effects. Consider first the expected output for each of these patterns, depending on whether Denasalization is phonetic or phonological:

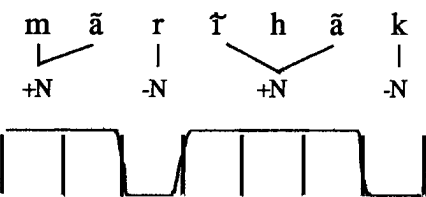
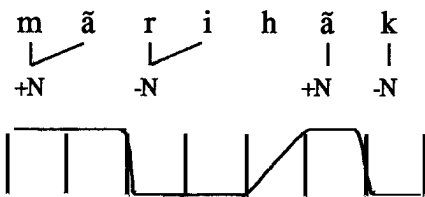
(40) Denasalization is phonological

Denasalization is phonetic

a. N=ar=VV e.g. /n=ar=aian/



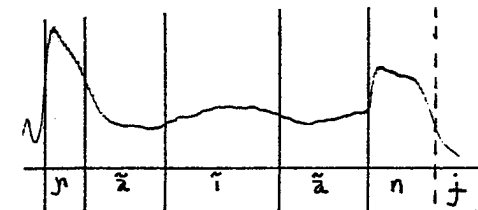
b. N=ar=VhV or N=ar=VĭV /m=ar=ihak/



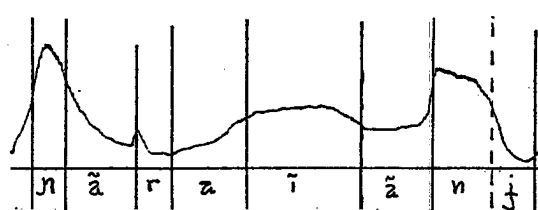
Following Robins' view, the effects of Denasalization should be categorical, affecting the full duration of the vowel (or most of it) in each of the cases. In the case of (40a), if Denasalization is phonological, we would expect to see a transition from oral to nasal at the end of the vowel (such as the transition seen in (35a & b) from the oral vowel to the final nasal); if it is phonetic, we would expect a transition at the beginning of the vowel. In the case of (40b), if Denasalization is phonological, we would expect to see no nasal flow on the vowel and transitional flow on the [h]; otherwise if the effect is phonetic, we would expect to see a transition at the beginning of the vowel with a fully nasalized [h]. A parallel example with glottal stop would be less informative, since we expect to see no nasal airflow irrespective of velum position or movement. Representative flow traces for these patterns are presented in (41), with corresponding unfixated forms.

(41) Flow traces for infixed /r/ patterns

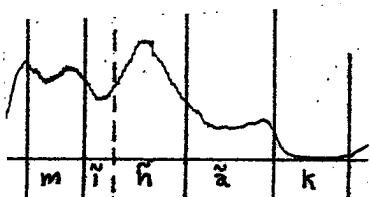
a. [nãrãñ] [S-L 4]



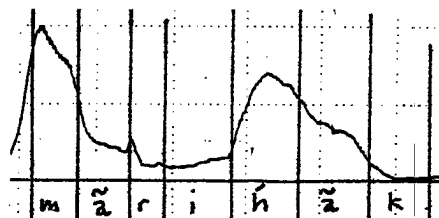
b. [nãraĩãñ] [S-L 2] (cf. 40a)



c. [mĩhãk] [S-L 1]



d. [mãrihãk] [S-L 2] (cf. 40b)



In (41b), we see that the [r] is oral and there is some slight nasalization on approximately the second half of the [a]. Looking at this form alone, it is difficult to determine if the effects of Denasalization are phonetic or phonological. Fortunately, the other pattern is more clear cut. In (41d), both the [r] and the following vowel are clearly oral, again compatible with the view that the vowel is [-nasal]. We see a rapid increase of nasal flow on the [h]. When this is factored with the high oral flow, there is observed to be a smooth increase in flow starting at the beginning of the [h], exactly what would be expected if Denasalization were phonological. We conclude therefore that in the case of /r/, there is indeed a phonological rule of Denasalization as described by Robins.

This has several consequences for our analysis. The simplest formulation of this rule is as a spreading rule, whereby [-nasal] spreads to the following vowel (but not a following nasal consonant). Unlike our rule of Nasal Spread, this is not a long distance rule and appears to be bound by the syllable, since longer distance effects of Nasal Spread are not undone. This rule results in a delinking of a multiply linked [+nasal] autosegment. (I do not have data to show what happens, if the following [+nasal] autosegment is not multiply linked, e.g. in a form such as /ŋ=ar=udag/ 'pursue' (active, plural).) The most straightforward assumption to account for this rule is that /r/ is indeed [-nasal] phonologically, since otherwise the autosegment necessary for spreading would not be present. Denasalization of a vowel after /r/ is evidence that /r/ is [-nasal], and this in turn is evidence that /r/ is also [-continuant]. Unlike oral stops, /r/ does not contrast for nasality; but it can bear a Nasal specification, because it is in the same natural class as the stops. If it were specified as [+continuant], we would expect it to remain unspecified for the feature Nasal due to the proposed configuration constraint. Based on this evidence, I conclude that /r/ and /l/ differ crucially in their phonological specification for the feature Continuant and that this accounts for their different phonetic realization, as well as the applicability or inapplicability of the phonological rule of Denasalization. We conclude then that /r/ patterns both phonologically and phonetically with the [-continuant] consonants, whereas /l/ patterns with the [+continuant] consonants.

I have assumed that in case of contrast, both [+nasal] and [-nasal] specification are present. Under this approach the feature Nasal would not be a monovalent feature as sometimes suggested in the literature (Itô and Mester 1989 and Steriade 1989). Contrast, in itself, is not evidence that a feature is not monovalent, but the possible reference to both values by phonological rules is. In Sundanese, we have argued that phonological rules make reference to both [+nasal] and [-nasal] specifications; therefore it follows that the feature Nasal is not a monovalent feature. This conclusion finds independent support in other phonological patterns of nasalization, which crucially involve spreading of a [-nasal] specification, notably the cases discussed by Anderson (1976).

In conclusion to this section, I present sample derivations of the infix patterns in (42):

(42) Sample derivations:

Input: a. p a u r
 R • • • •
 | | | |
 SL • • • •
 | |
 +N -N

b. m i h a k
 • • • •
 | | | |
 • • • •
 | |
 +N -N

Nasal Spread: p a u r
 ↙ ↘
 +N
 R • • • •
 | | | |
 SL • • • •
 ↙ ↘
 +N -N

m i h a k
 • • • •
 | | | |
 • • • •
 ↙ ↘
 +N -N

Infixation: p=a l=a u r
 R • • • •
 | | | | | |
 SL • • • •
 | # V |
 +N +N -N

m=a r=i h a k
 • • • • • •
 | | | | | |
 • • • • • •
 | | √ |
 +N -N +N -N

Nasal Spread: p=a l=a u r
 ↙ ↘
 +N
 R • • • •
 | | | | | |
 SL • • • •
 ↙ ↘ # V |
 +N +N -N

m=a r=i h a k
 • • • • • •
 | | | | | |
 • • • • • •
 ↙ ↘ | √ |
 +N -N +N -N

Denasalization: —
 ↙ ↘
 -N +N

m=a r=i h a k
 • • • • • •
 | | | | | |
 • • • • • •
 √ ↘ ↘
 +N -N +N -N

Default Fill-in: —
 ØN → -N

Phonological Output: p a l a u r
 R • • • • • •
 | | | | | |
 SL • • • • • •
 √ √ |
 +N +N -N

m a r i h a k
 • • • • • •
 | | | | | |
 • • • • • •
 √ √ | |
 +N -N +N -N

Phonetic Implementation:

Target Assignment:



Interpolation:



ɲ ǣ ĩ ǣ ʊ r m ǣ r i ã ǣ k

In (42a), the derivation is basically the same as seen above, since Denasalization is not applicable. In (42b), Denasalization applies. It must apply after Infixation; I assume that it is post-lexical. (In which case, it would be expected to apply across word boundaries; no evidence exists to support or refute this prediction.)

It might be assumed that Denasalization rather than Default Fill-in is responsible for providing values for unspecified vowels. It would potentially account for forms such as /ɲatur/, but could not account for the phonologically [-nasal] vowels in forms involving /l/ or the glides, e.g. /ɲiwat/, /ɲuliat/. These cases provide evidence for the Default Fill-in rule. The forms above in (35a) and (35b) also offer additional support for the Default Fill-in rule for vowels not affected by Nasal Spread. In each case, the vowel after the liquid is oral, even though followed by another nasal. This is most striking in the case of [pǎŋlĩŋ]. The [l] is partially nasalized, argued to be due to the fact that it is unspecified, so only if the vowel were specified as [-nasal] can we account for the fact that there is not nasalization straight through both the [l] and [i]. This case is especially convincing because of the high oral impedance of /i/. If the velum were open at all, we would expect to see some nasal flow.

In this and the preceding section, we have pursued several important details of the analysis, focusing on the phonetic realization of phonologically transparent segments as well as the different phonetic realization of nasality on /r/ and /l/. We conclude that the observed facts follow from the phonological and phonetic analyses proposed in §3.3.

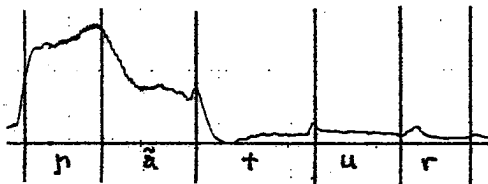
3.6. Issues of rule interactions

The position taken in this study is that phonological rules and phonetic rules differ in that what they manipulate is different. Phonological rules manipulate discrete, categorical representations, whereas phonetic rules manipulate quantitative ones. It is argued that there are different formal mechanisms involved. One goal of this study is to seek a principled characterization of the difference between phonological and phonetic rules which follows from these different properties. Some possible characterizations were discussed in Chapter 1. It was argued that phonological rules should result in categorical effects whereas phonetic rules are expected to result in gradient effects. Nasalization in Sundanese offers support for this distinction. It is a particularly nice example as both types of rules are exemplified and there is independent

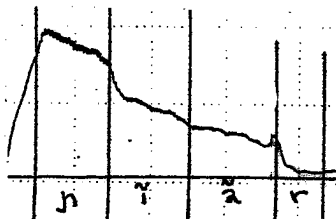
evidence for the characterization of the rules as being phonological or phonetic. First it is worth noting that an underlying [+nasal] specification is realized in a quite categorical fashion. A nasal consonant is nasal in a significant way for its full duration. This was observed in the forms presented in §3.3 - 3.5. It is important to note, though, that a fully nasalized segment may still display a cline-like quality in its nasal flow.

The rule of Nasal Spread was shown to be part of the deep phonology of Sundanese, by its interaction with morphology. There is thus no question about it being a phonological rule, not a phonetic one. We saw that this rule resulted in categorical outputs of nasalization as predicted for a phonological rule. This can be seen in the nasalization of the [a] following the initial nasal consonant in (43a) as well as in the nasalization of a sequence of vowels (43b & c). There is a significant amount of nasal flow throughout the full duration of the vowels following the nasal, as a result of the rule of Nasal Spread.

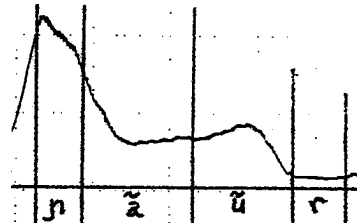
(43) a. [ŋãtur] [S-L 1]



b. [ɲfãr] [S-L 2]



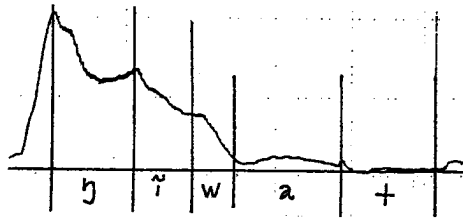
c. [ɲãũr] [S-L 2]



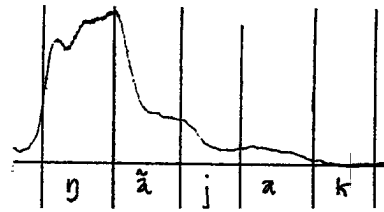
Robins remarks that his speaker was sensitive to the nasalization of vowels in Sundanese, evidence that the output, though not distinctive, is categorical. The general observation that emerges is that nasals are fully nasalized throughout their duration and so are vowels, when following a nasal, even in a long sequence. This leaves aside many important smaller details, but nevertheless, it is clear that the phonological rule of Nasal Spread results in categorical, not gradient, effects.

We also observed some gradient effects of nasalization in Sundanese, which include the partial nasalization of /l/ and glides in forms such as [ɲfãwat], [ɲãjak], and [ɲũliat], presented above in (16) and repeated here in (44).

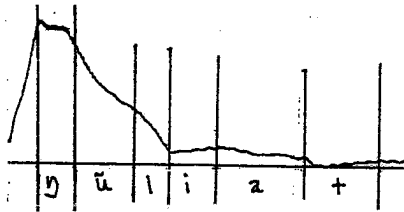
(44) a. [ŋfʷat] [S-L 1]



b. [ŋãjak] [S-L 4]



c. [ŋɔliat] [S-L 2]



These gradient effects are independent from Nasal Spread; since as shown in (5), both /l/ and the glides block Nasal Spread phonologically. It was argued that these gradient effects were a result of phonetic implementation, more precisely interpolation through a segment unspecified for the feature Nasal from a [+nasal] specification to a [-nasal] specification. Not surprisingly the partial nasalization of these segments is not something that the native speakers that I recorded were sensitive to. The gradient effects have precisely the expected characteristics. Thus, we observe both categorial and gradient outputs of nasalization in Sundanese. The outputs of the phonological rule of Nasal Spread and of the phonetic implementation differ as predicted, with Nasal Spread resulting in significant nasalization of full segments and phonetic implementation resulting in gradient effects, supporting the notion of a grammatical division in phonological and phonetic rule types. Furthermore, it is seen that this difference follows directly from the mechanisms involved in phonological and phonetic rules respectively.

This distinction of categorial vs. gradient application may serve as a useful heuristic for identifying the source of certain effects. Thus for example, the fact that there was no gradient flow on vowels following an /l/ or glide was taken as evidence for a phonological default fill-in rule assigning [-nasal] specifications to unspecified vowels. Yet this distinction must be applied cautiously and wherever possible with independent support. We have seen somewhat cline-like effects during a specified segment, e.g. on the [ŋ]'s and [a]'s in (43). Another case resulting in gradient effects is the effect of glottalization on a [+nasal] vowel as exemplified above in (25) and (26). We have also seen apparently categorial effects as a result of phonetic implementation. For example, in the case of infixed /l/, we observe nasalization straight through the /l/ –which appears quite categorial in nature, due to the interpolation between two high targets through an unspecified span.

3.7. Summary of the chapter

In this chapter, both a phonological and phonetic analysis of the facts of nasalization in Sundanese were proposed. It was argued that the facts could be accounted for in an insightful fashion following certain basic assumptions. These include the interleaving of phonology and

morphology as the correct view of the phonological cycle and the argument that the blocking effects of segments involving predictable feature values must be due to general structural principles such as the proposed configuration constraint rather than redundant feature specifications. The striking facts of /l/ and glides blocking Nasal Spread in the phonology, but being amenable to nasalization in the phonetics, follow from the above views of phonology coupled with the conclusion that there is not necessarily full specification leaving the phonology. The observed output is accounted for as phonetic interpolation through a phonologically unspecified span. That this is the correct account of the facts of nasalization in Sundanese offers strong evidence for the general view that there is not necessarily full specification leaving the phonology, since in this case, full specification at the output of the phonology leads to empirically incorrect results.

We conclude that phonetically transparent segments may result either from the presence of the proposed configuration constraint (the case of /l/ and glides) or may be due to structural properties of the phonology (the case of /h/ and glottal stop). Although the phonological behavior of these two classes of segments is very different, their phonetic transparency receives a unified treatment, following the assumption that there is not full specification leaving the phonology. Additionally, it was argued that the observed phonetic differences between /r/ and /l/ with respect to nasalization in Sundanese is due to differences in their phonological specifications, a conclusion supported by the observed facts on Denasalization.

The idea that phonology results in categorial effects, whereas phonetics results in gradient effects, is not only descriptively adequate for the facts of nasalization in Sundanese, but receives independent support from the evidence of rule ordering.

In this chapter, we focused on the characterization of phonological vs. phonetic processes and representation, using a simplistic view of phonetic implementation. In the next chapter, we turn our attention to the specifics of phonetic implementation, the nature of targets, phonetic constraints and interpolation.

CHAPTER 4 FRENCH

In the previous chapter, a first approach to the phonetic implementation of the feature Nasal was incorporated in the discussion of Sundanese. The details of implementation were left aside. The goal of this chapter is to construct a more comprehensive theory of implementation in order to account for the phonetic implementation of Nasal in French. Particular issues to be addressed include the nature of targets, the location of turning points and patterns of interpolation. A more general issue is the question of phonetic constraints: what kinds of restrictions might be imposed on phonetic implementation that are independent of feature specification? Additional issues emerge as we examine the French data, including an observed asymmetry between anticipatory and carryover nasalization, and the importance of syllable structure.

The structure of this chapter is as follows. First in §4.1, we discuss some general issues of phonetic implementation. In §4.2, we consider possible phonological representations for the feature Nasal in French. In §4.3, the data collected for this study are described. In §4.4 - 4.6, we discuss the cases and construct an analysis. In §4.7, we consider the implications of the analysis and we conclude the chapter with a brief summary in §4.8.

4.1. Some issues of phonetic implementation

The implementation of a particular feature is often assumed to be straightforward, following from general universal principles of implementation (although we do not happen to know what these principles are); yet as discussed below, the actual details of implementation are quite complex. In this chapter, both representations and rules will be proposed which together account for the attested outputs (as represented indirectly by nasal airflow measures) of a systematic set of cases in French. The analysis is necessarily language specific, although we will see that it is, for the most part, compatible with the analysis of Nasal for Sundanese in Chapter 3. The proposed analysis will be extended to English in Chapter 5, at which point we can start to consider which aspects are language specific and which aspects are perhaps universal.

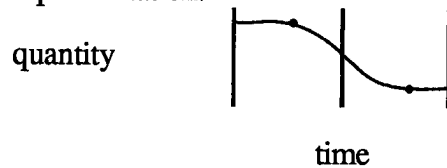
4.1.1. Targets: points vs. inherent durations

In Chapter 3, it was assumed that phonological feature specifications were mapped to targets which had inherent durations lasting most of the duration of the segment. The concepts of inherent duration and "most of the duration of a segment" were not formalized, but such targets were seen to closely model the shape of the observed Sundanese nasal flow traces. Before turning to the specifics of French, it is worth considering first some of the logical possibilities of how feature values might be translated into phonetic targets. Our assumptions so far are that the output of the phonology consists of feature values in a hierarchical relationship associated with abstract timing units. In the mapping to the phonetics, each segment gets a real time. There is presumably a list of look-up values; such values might be in terms of a percentage of a segment or absolute duration. Each feature specification gets a target. So far we have been quite vague about the nature of targets, but clearly targets must be realized in both time and space. There are two aspects of the timing of targets that need to be considered. First what is their duration: are they timeless points or do they have an inherent duration? Second, how are they located relative to other aspects of the speech event (in an abstract sense, with respect to a particular segment or segments, or in a more

physical sense, in their coordination with other articulatory movements)? One view often assumed is that targets consist of a single point located in the middle of the segment (e.g. Pierrehumbert 1980, Keating 1985a). This view is a restricted one, which avoids complications with either of the aspects of timing just noted. Following such a view, we expect to see phonetic patterns such as the one schematized in (1).

(1) Phonological Output: x x
 | |
 +N -N

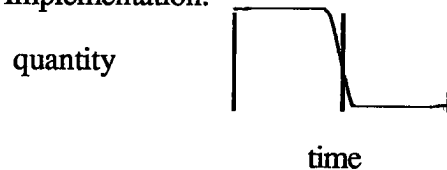
Phonetic Implementation:



Here only the middle of the segment would necessarily have a particular target value; most of the duration of the segment might be taken up in changing from a previous, or to a following, target. Consider now the possibility that a specified feature translates into a target with an inherent duration, as suggested by Pierrehumbert and Beckman (1988). Inherent durations might be related to the duration of a segment (e.g. Keating 1988a), or might be instantiated in terms of absolute timing. A target with an inherent duration for most of the duration of a segment would result if an abstract value with abstract timing gets "stretched out" when it is realized in real time, as schematized in (2).

(2) Phonological Output: x x
 | |
 +N -N

Phonetic Implementation:



The pattern in (2) is more appropriate than (1) in accounting for the observed patterns in Sundanese, e.g. /ŋātur/, where the nasal segments are observed to be nasal throughout their duration and the oral segments (those argued to be [-nasal] phonologically) are seen to be oral for all or most of their duration.

It might be assumed that the kind of difference between (1) and (2) is due in part to the phonological use of the feature Nasal in a particular language. For example, for vowels in a language like English where no contrast exists, it might be assumed that we do not need inherent duration for targets for vowels (assuming that these segments are specified at all – an issue that will be taken up in Chapter 5); whereas in French, there is a contrast, so on this view, these targets would involve inherent duration. Language differences in the nature of target assignment of this

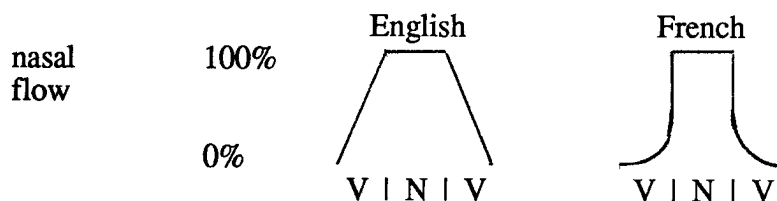
sort were not observed in the present study. It is argued below that the view of targets as full segments is basically correct.

4.1.2. Why French?

French is a useful starting point in the study of the phonetic implementation of the feature Nasal, since it imposes maximal constraints on the system phonologically. As noted in Chapter 1, in addition to a contrast between oral and nasal segments for consonants, at least a surface contrast exists for vowels as well. Furthermore, French maintains the contrast even when adjacent to nasal consonants. French is generally assumed, therefore, to have very little coarticulatory effects of nasalization.

To make this point clearer, contrast French with a language like English. English has been observed to have extensive nasalization of vowels adjacent to a nasal consonant. Such contextual effects are assumed to be tolerated precisely because the feature Nasal is not contrastive for vowels. On the other hand, more limited effects are expected in a language like French, where there is a contrast for Nasal for consonants, and at least a surface contrast for Nasal for the vowels as well. Either this contrast is expected to be neutralized adjacent to nasal consonants or contextual effects are expected to be very restricted, limited only to transitions at the edge of segments (following the general hypothesis that contrast constrains allophonic variability, cf. Lindblom 1983, Manuel and Krakow 1984, Keating 1988a). Based on these assumptions, we might expect the following schematic phonetic outputs, for a vowel-nasal-vowel (VNV) sequence in English and French:

(3) Hypothetical phonetic output



In the first case, where no possible contrast exists, there is no limit on coarticulation and some level of nasalization might occur throughout both the preceding and following vowels; whereas, in the second case, where there is a possible contrast, only limited effects of hooking up the segments would be expected. In the framework proposed here, this pattern would be predicted if vowels in English were unspecified for the feature Nasal, whereas oral vowels in French were specified as [-nasal].

Rather surprisingly, the latter is not at all the observed pattern for French. The coarticulatory effects are not just transitional, nor purely mechanical. We will see that nasalization occurs to varying degrees on phonologically oral vowels (and certain consonants as well) adjacent to nasal consonants. Looking in detail at patterns of nasal flow, we observe significantly more flow than "needs to be there" mechanically. The notion of what "needs to be there" can be defined by study of the speed of velum movement (such as reported in Hudgins and Stetson 1937, Ohala 1971, 1975 and Clumeck 1976) and also by comparing those contexts within French where movement is

very fast, in contrast to those cases where it is potentially slower, e.g. the transition in a sequence such as [nt] compared with [nV], where the transition is observed to be much more rapid in the former case than the latter. Such differences need to be accounted for in an adequate model of phonetic implementation.

4.2. Phonological patterning of the feature Nasal in French

4.2.1. The basic inventories

The consonant inventory of French is presented in (4).

(4) French consonants

	labial	dental	alv-pal	palatal	velar	uvular
stops						
voiceless	p	[t]			k	
voiced	[b]	[d]			g	
nasals	[m]	[n]		ɲ		
fricatives						
voiceless	f	s	ʃ			
voiced	v	z	ʒ			ʁ
liquid (lateral)		[l]				
glides	ɥ			[j]	w	

The sounds enclosed in boxes in (4) are those chosen as representatives of their natural classes for the present study; for the most part coronals were studied. As in the vast majority of the world's languages, there is a contrast between nasal and oral stops in French, as exemplified by minimal pairs such as the following:

(5)	<i>dé</i>	[de]	'dice'	~	<i>nez</i>	[ne]	'nose'
	<i>bain</i>	[bɛ̃]	'bath'	~	<i>main</i>	[mɛ̃]	'hand'

In some descriptions of French, [ɲ] is also listed as a member of the nasal series. Its status is very marginal, due exclusively to recent borrowing. It is therefore ignored in this discussion.

The vowel inventory of French is presented in (6):

(6) French vowels

		Oral				Nasal	
		front		back		front	back
		-R	+R				
high		i	y	u	rounded	(œ)	ɔ̃
mid	higher	e	ø	o	unrounded	ɛ̃	ã
	lower	ɛ	œ ə	ɔ			
low				a			

The height of mid vowels is predictable in most cases, with the higher mid phones occurring in open syllables and the lower mid ones in closed ones. There is a surface contrast between nasal and oral vowels as exemplified by the following minimal and near-minimal pairs:

(7)	<i>pas</i>	[pa]	'step'	~	<i>pan</i>	[pã]	'section'
	<i>dais</i>	[dɛ]	'canopy'	~	<i>daim</i>	[dɛ̃]	'deer'
	<i>botte</i>	[bɔt]	'boot'	~	<i>bon</i>	[bɔ̃]	'good' (m.)
	<i>eux</i>	[ø]	'they'	~	<i>un</i>	[œ̃]	'a' (m.)

The status of [œ̃] is more marginal than that of the other nasal vowels. For many speakers there are only three nasal vowels, with [œ̃] being replaced by the unrounded [ɛ̃].

The phonemic status of the nasal vowels is much more controversial than that of the nasal consonants. The nasal vowels derive historically from vowel-nasal sequences, with nasalization of the vowel and subsequent deletion of the nasal. There has been extensive debate in the literature as to whether the nasal vowels should be viewed as synchronically derived from underlying vowel-nasal sequences as well.

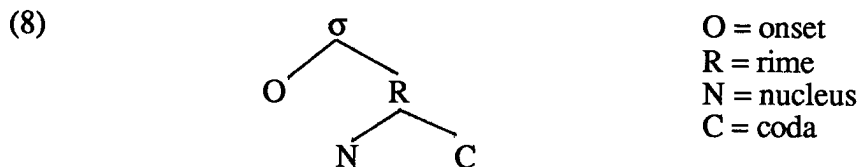
A wide range of analyses have been proposed arguing for an abstract approach (cf. Schane 1968, Dell 1970, Selkirk 1972, and more recently Prunet 1986 and Piggott 1987). Such approaches capture a wide range of facts about observed derivational relationships between certain nasal vowel and oral vowel-nasal consonant sequences. Problems for the abstract view include the very different vowel quality of certain of the pairs of oral and nasal vowels argued to be in a derivational relationship, the non-alternating nasal vowels in liaison in some dialects, and cases which violate the generally observed phonotactic distribution of nasal vowels in forms such as *Panhard* [pãar] '(French car make)' (see Tranel 1981 for a clear discussion of the issues involved). Selkirk (1972) argues that only some nasal vowels, those displaying alternations, should be derived; others she assumes are underlying. Morin (1972) also argues that at least some nasal vowels are underlying. On the other hand, many have argued for a more concrete analysis, assuming that the historical development of nasal vowels need not be recapitulated by the synchronic analysis (cf. Tranel 1981, Benguerel et al. 1977a). This avoids the problems above, but either does not allow the formal encoding of the systematic relationship between derivationally related oral and nasal forms or requires the representation of this relationship in some very different

way. Any attempt at a resolution of this involved and complex debate would take us far beyond the scope of this study.

What is important for our purposes is the observation that there is indeed a surface contrast between oral and nasal vowels in French. Furthermore, if derived, the nasal vowels must be derived in the deep phonology, since they involve exceptions and can be followed by both phonology and morphology. Following the proposal of Mohanan and Mohanan (1984) and Mohanan (1986), it is not clear if the nasal vowels of French are members of the "underlying alphabet", but they clearly are members of the "lexical alphabet". We are concerned here most basically with the mapping from the output of the phonology to the phonetics; the fact that the nasal vowels play an integral role in the phonology indicates that they are indeed entities leaving the phonology that must be mapped to the phonetics.

4.2.2. Syllable structure in French

It is important to consider syllable structure in French, in order to be able to evaluate its role in implementation of the feature Nasal. The syllable structure and terminology that I will be assuming are presented in (8). (Nothing hinges on this particular view of the syllable.)



The basic patterns of syllable structure in French are fairly straightforward, with a tendency toward open syllables. An onset may include from zero to three consonants, most commonly one or two, following typical sonority constraints. A coda, if present, consists of usually one consonant, but sometimes two. A nasal consonant can occur in either onset or coda position. If in onset position, a nasal consonant must be syllable initial and can only be followed by a glide (assumed here to be part of the onset), e.g. *nez* [ne] 'nose', *nier* [nje] 'deny'. In coda position, no other consonant may follow a nasal consonant. If a nasal consonant is syllable final preceding a vowel initial word, it will be resyllabified as the onset of the next syllable (traditionally termed "enchaînement" in French), e.g. *bonne ode* /bɔn od/ [bɔʃnod] 'good ode'. A syllable final nasal consonant (not resyllabified) is often followed by a brief schwa, e.g. *bonne* /bɔn/ [bɔnə] (thereby making its syllable affiliation debatable.) In a vowel-vowel sequence, either the vowels belong to different syllables, or the first vowel is realized as a glide. In such cases, the glide can be argued to be part of the preceding onset, since such a glide affects the possible onsets (with the exception of /w/ when preceding /a/, which has special phonotactics). A nasal vowel is necessarily the full nucleus and can be followed by a more limited range of codas than other vowels (as observed by Levin 1988), only an oral obstruent, most usually a stop. But of course a nasal vowel can be followed by a full range of consonants across a syllable boundary. (For a fuller description of syllable structure in French, see Levin 1988 and Plénat 1987.)

4.2.3. Possible phonological representations for the feature Nasal in French

As discussed in Chapter 1, most current views of phonology assume at least some degree of underspecification. It was argued in Chapter 3 that only a theory that assumed the possibility of some unspecified feature values at the output of the phonology (in the cases of redundant or predictable specification) was adequate to account for the facts of nasalization in Sundanese. We argued that glides and /l/, predictably not nasal due to their [+continuant] specification, remained unspecified throughout the phonology and into the phonetics. It was assumed that [-continuant] consonants as a class were specified, and vowels underlyingly unspecified were specified by phonological rule, either the rule of Nasal Spread, if applicable, or otherwise the default assignment of [-nasal]. We turn now to a brief consideration of the expected phonological specifications for the feature Nasal in French.

Any model requiring full specification at the output of the phonology must be rejected, as such a view was shown to be empirically inadequate to account for the facts of nasalization in Sundanese. Such a view would obtain with either full specification throughout the phonology (e.g. SPE) or initial underspecification plus obligatory fill-in rules (e.g. Archangeli and Pulleyblank 1986, but modified in their more recent work, see Archangeli 1988). The fact that full specification leaving the phonology is rejected is quite important. In addition to strong empirical evidence for rejecting this assumption, methodological motivation also exists for rejecting it, if we do indeed want to find a connection between phonology and phonetics. If there were necessarily full specification leaving the phonology, phonological underspecification could play no role in phonetic implementation. The question of degree and type of specification only becomes an interesting one if we reject the notion of automatic full specification leaving the phonology.

It is an empirical question whether, in a given case, underlyingly unspecified values get filled in during the course of the phonological derivation or not. For example, in Chapter 3 in our analysis of Sundanese, we observed both of these outcomes: /l/s and glides remained unspecified throughout the phonology, whereas vowels, underlyingly unspecified, if not affected by the rule of Nasal Spread, received default [-nasal] phonological specifications.

It is the nature of the representation at the output of the phonology, not the underlying representation, that is of greatest significance to us here, since it must be the output of the phonology that the phonetics interprets. We need, therefore, to look for phonological evidence of the application of phonological rules, default fill-in or otherwise, to correctly interpret the level of specification at the output of the phonology.

If something is specified underlyingly, it seems reasonable to assume that usually it will also be specified at the output of the phonology. (There are presumably cases of phonological feature loss which do not also involve spreading. In these cases, the output might be less specified than the underlying representation. This might include certain cases of weakening, e.g. [s] → [h]. One could also imagine cases of loss of a marked value, later filled in by default.) But if something is unspecified to begin with, as noted above, it does not follow that it will remain unspecified. Underspecification in the phonetics implies underspecification in the phonology, but specification in the phonetics could result from different sources.

If French is like Sundanese, we would expect the phonological specifications at the output of the phonology in French as summarized in (9):

(9) Output of the phonology the feature Nasal in French

	Class	Output
Consonants:		
	oral stops	
[-continuant]	[-voice] (T)	[-nasal]
	[+voice] (D)	[-nasal]
	nasal consonants (N)	[+nasal]
	liquids (L)	[Ønasal]
[+continuant]	fricatives (F)	[Ønasal]
	glides (G)	[Ønasal]
Vowels:	oral vowels (V)	[-nasal]
	nasal vowels (∇)	[+nasal]

Interpreting Steriade's (1987a) view of contrast within a class quite broadly, we assume nasal consonants are underlyingly specified as [+nasal] and that oral stops are specified as [-nasal] since they contrast with nasal consonants, in the class of [-continuant] segments. For the [+continuant] consonants, no contrast exists for the feature Nasal, so these segments would be assumed to be unspecified for the feature Nasal, underlyingly and at the output of the phonology. (It is assumed that the proposed configuration constraint – the feature Nasal cannot co-occur with [+continuant, +consonantal] – should hold in French as well.) Within the vowels, a (surface) contrast exists for at least some of the vowels. The nasal vowels would clearly be specified as [+nasal] and we assume, based on this surface contrast that non-nasal vowels are specified as [-nasal] at the output of the phonology. We take these specifications as a starting point, but in each case look for both phonological and phonetic evidence to substantiate these views.

4.3. The data

One of the goals of this part of the study was the creation of a systematic data set to examine both nasal and oral segments in a variety of segmental contexts in French. Certain similar patterns are described elsewhere in the literature, using a variety of methodologies. Most notably, previous work relating to nasalization in French includes the x-ray studies of Blichler-Labaeye (1970), Rochette (1973), Botherel et al. (1986) and Delattre (1965, 1968, among others), and other physiological methodologies in the studies of Benguerel (1974) and Benguerel et al. (1977a and b).

Yet no overall picture can be constructed from the data on French in the literature. None of the studies offers an extensive enough data set to address the issues raised in this study. (The limit on amount of data collected in some of the studies is due in part to methodological considerations that made collection of a large corpus difficult, or, in the case of x-rays, dangerous.) Additionally

few of the data show change over time, so they cannot be considered in the same way as the data in the present study.

Although the previous studies of nasalization in French are not sufficient to examine the issues under consideration here, some of the data are relevant and important. We will see that they validate many of the observations made in the present study. These studies are mentioned where relevant to the discussion and are discussed in light of the results of the present study in §4.7.2.

For this study, an extensive minimally contrasting data set was constructed in order to discuss a wide range of phonological contexts and also to allow cross-linguistic comparison.

The study of French reported on here is based primarily on recordings of two male speakers of European French, one from Paris and one from Aix-en-Provence, following the methodology described in Chapter 2. Both speak what is termed "Standard French", although, in each case, there might be some subtle dialect influence. In subsequent discussion, when I refer to "French", it is the speech of these two speakers which is being referred to. As noted above, ideally several speakers would be studied in order to identify language differences in contrast to dialect or speaker differences. Two other speakers were recorded for a subset of the data only, but since only a subset of the data is available, they are not reported on here. Yet it is worth noting that the data from these additional speakers are consistent with the data from the speakers being reported on. The observed patterns are also consistent with data cited in other studies.

Each speaker was recorded in two sessions, due to the size of the data set being collected. All forms collected in the present study are real words of French and were recorded as members of minimal pairs or sets. The word list is presented in Appendix B. (This list combines the forms recorded in each of the two sessions.) The two speakers reported on here are very similar in most respects; they appear to use the same general rules, although they differ in some of the smaller details. Most of the discussion will focus on one speaker (F-D), but reference will be made to the second speaker (F-F) where relevant.

We will look at a systematic set of cases in which a change in velum position is expected: oral-nasal sequences (anticipatory cases) or nasal-oral sequences (carryover cases). Forms involving oral-oral sequences were collected as controls and to allow an effective baseline to be set (as described in Chapter 2) and some nasal-nasal sequences were collected as well. Both such types of patterns were unilluminating in precisely the expected way: oral-oral sequences showed no significant nasalization and nasal-nasal sequences remained consistently nasalized as expected. We focus, therefore, on patterns where velum movement is expected, considering both anticipatory cases (-N +N or \emptyset N +N) and carryover cases (+N -N or +N \emptyset N) in turn.

We consider the classes of segments described in §4.2 above: [+nasal] as exemplified by both N's and ∇ 's; oral vowels and oral stops, both voiced, and voiceless and oral vowels, assumed to be [-nasal]; and glides and liquids, assumed to be [\emptyset nasal]. (Data collected for fricatives was too limited to draw conclusions about their behavior as a class and they are therefore not included in our discussion.) In order to study both the nature of phonetic targets and patterns of interpolation, we are interested in steady state portions of phonetic realization as well as portions of change over time.

As we examine the cases, first anticipatory, then carryover, then oral segments in between [+nasal] specifications, we will construct an analysis to account for the observed mapping from the

phonology to the phonetics. The structure of the presentation is as follows. The basic analysis will be presented in §4.4, based on the anticipatory cases. It will be argued that targets with inherent duration can account for the observed patterns. A specification for the feature Nasal, whether plus or minus, maps to such a target. Such a view necessitates a theory of transitions as well. It will be seen that glides and /l/ are not always unspecified as predicted; rather in syllable initial position they surface as [-nasal], argued to be due to a syllable initial default fill-in rule. In §4.5, the analysis will be extended to account for the asymmetry observed between anticipatory and carryover cases. This asymmetry will be accounted for with a rule of [-Nasal] Deletion following a [+nasal] specification. In §4.6, when we examine the most constrained case, an oral segment between two [+nasal] specifications, it will be argued that even in the case of sounds unspecified leaving the phonology, the phonetics may still impose requirements.

4.4. Target assignment and transitions

4.4.1. -N +N patterns

We consider first cases of [-nasal] [+nasal] sequences where we assume, based on contrast, that the oral segments in question are indeed specified as [-nasal]. These cases will be exemplified by both stops and vowels preceding both nasal consonants and nasal vowels (SN, VN, S \check{V} , and V \check{V}). Consider the expected output for the anticipatory pattern schematized in (10):

(10)	targets as points	targets with inherent duration
Phonological	x x	x x
Output:		
	-N +N	-N +N

Phonetic Implementation:

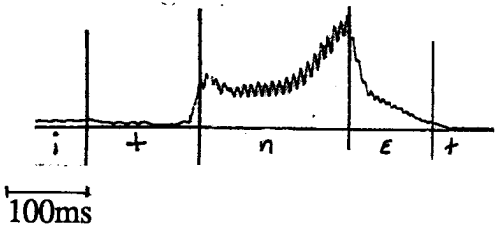


As illustrated in (10a), if the targets are timeless points, we do not necessarily expect to observe any steady state portion of flow; whereas if the targets do have inherent duration, as schematized in (10b), we would expect to observe steady state portions of the flow. Representative examples are presented in (11):

(11) -N +N patterns

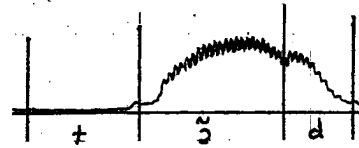
a. SN

i. (di)tes net /t#net/ 'say clean' [F-D 5]

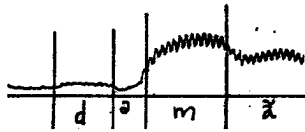


c. SṼ

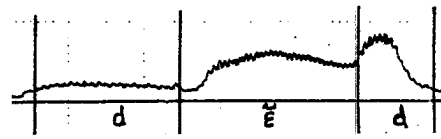
i. thon (deux) /tʃ#d/ 'tuna' [F-D 2]



ii. (lai)dement /d^əmã/ 'in an ugly way' [F-D 4]



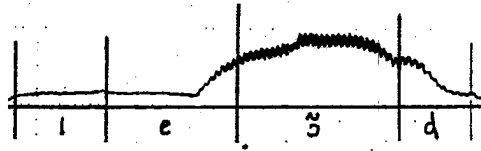
ii. daim (deux) /dɛ#d/ 'deer' [F-D 5]



b. VN bonnet /bɔnɛ/ 'bonnet' [F-D 3]



d. VṼ Leon /leʒ/ 'Leon' [F-D 1]



Consider first the SN cases. In (11ai) we see a case of a /t-n/ sequence. We observe no nasal flow during the /t/ until the release of the stop. The flow increases rapidly during the release and is significant by the onset of voicing (taken to be the beginning of the nasal segment, as described in Chapter 2). A slight spike in the flow occurs right before the onset of voicing in many tokens, resulting, perhaps, from the decrease in overall airflow at the onset of voicing. The /n/ is significantly nasal throughout its full duration. The flow during the nasal consonant in these cases is fairly constant, but in most cases continues to rise slightly until the end of the nasal consonant, at which point a slight peak is often observed. The examples in the data set elicited with /d-N/ clusters were in both cases pronounced with a brief schwa between the consonants. One such example is shown in (11aai). In all such tokens, the onset of nasal airflow is at the end of the schwa. Further investigation is needed of cases without a schwa. (Some such cases, DN without an intervening schwa, occur in Rochette 1973.)

In (11b), a VN sequence is presented. The vowel remains oral for most of its duration, until toward the end of the vowel, at which point a clear turning point occurs where nasal flow starts; the transition from oral to nasal starts during the vowel with a rapid increase in nasal flow at the point of oral closure, as expected, since at this point all airflow must be through the nose. Flow is a significant by the beginning of the nasal consonant (measured from the oral closure) and remains fairly constant throughout the segment. The observed pattern is very similar to that of SN, with the transition in both cases occurring at the end of the oral segment and completed by the beginning

of the nasal segment. Unlike the /t-n/ case, there is never a spike at the onset of nasalization, but rather a fairly distinct turning point. The location of the turning point is to some degree affected by syllable structure and stress, an issue we return to in §4.4.4.

In $S\check{V}$ cases, exemplified by /tʃ/ and /dʒ/ in (11ci and ii) respectively, the stop, voiced or voiceless, remains oral throughout. A brief delay of the onset of nasalization of about 20-30ms is observed after the stop release, at which point we see a pronounced onset of nasalization, reaching about two thirds to three fourths of its maximum amplitude within about 20-30ms. A fairly constant level of nasalization is maintained for the duration of the vowel. (This delay is consistent with observations in previous studies, cf. Benguerel et al. 1977a, Briclher-Labaeye 1970, Al-Bamerni 1983, and Rochette 1973 in some tokens.)

A systematic difference obtains between the transition of the oral stop and a following segment, depending on whether the [+nasal] segment is a consonant or a vowel. In the case of a following nasal vowel, (as exemplified in (11c)), the stop release is completely oral and only after onset of the vowel does nasalization occur; whereas in the case of a following nasal consonant (11a), the onset of nasalization is during the release itself.

The amplitude of flow on /ʃ/ and /ʒ/ is quite different, seen in (11ci and 11cii) respectively. The amplitude of flow on /ʃ/ is comparable to that observed on nasal consonants, whereas that on /ʒ/ is significantly lower. These differences are due to impedance effects, as discussed in Chapter 2. We expect the raw flow observed on a nasal vowel to be significantly lower than on a nasal consonant, such as the relationship between /n/ and /ɛ/. The amplitude on /ʃ/ is higher than on /ʒ/ since it involves greater constriction close to the velum. The level in these cases is higher than would a priori be expected and is due to extreme oral constriction, as inferred from strikingly low rates of oral flow during /ʃ/. This conclusion is supported by the observations of velum height in the fiberoptic study of Benguerel et al. (1977a), where it was observed that /ɔ/ and /ʃ/ had the highest velum positions of the vowels of French studied, including both rounded and unrounded high vowels.

In the $V\check{V}$ cases, exemplified in (11d), the timing of the transition is very much like that seen above in the VN cases, with a turning point late in the (oral) vowel (in this case approximately two-thirds of way through). The nasal vowel is nasalized throughout. The onset of flow is less rapid than that observed in the $S\check{V}$ cases, but the shape of the curve is similar.

In all of these cases, the oral segment is oral for most or all of its duration and the nasal segment, whether consonant or vowel, is nasal for most or all of its duration. The preceding segmental context affects the timing and shape of the transition into a nasal vowel, but not into a nasal consonant. In other words, all of these segments, both nasal and oral, are characterized by a steady state portion for most of the duration of each segment and in all cases the transition is a rapid one.

4.4.2. Targets with inherent duration

The observed output in these cases can be accounted for in a target-interpolation model assuming that targets have inherent duration. The patterns of flow are similar to those observed in

a nasal consonant has priority or dominance over its left edge, no matter what the preceding segment is. The [+nasal] specification also has priority in the case of a V \checkmark sequence. In other words, the onset of nasal flow occurs fully during the transition of the preceding segment and not during the nasal consonant or vowel itself. In contrast, in the case of a S \checkmark sequence, it is the stop that has priority, with the onset of nasalization occurring during the beginning of the vowel (its left edge transition), not during the release of the stop. To account for the cases observed so far, I propose the following two priority statements:

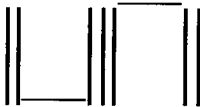


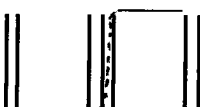
- (13) a. [-continuant] > [+continuant]
 b. [+nasal] > [-nasal]

where a. has precedence over b.

The first statement accounts for the cases where continuancy differs between the two adjacent segments and the second statement accounts for the cases where the continuancy is the same. These two statements together account for the fact that the nasal segment is dominant in all the cases except in the S \checkmark , where it is the stop that has dominance. (We return below to the \checkmark d cases, apparent exceptions to these generalizations.) The first statement may be a consequence of the important role that closure and release are observed to play in phonetic implementation (see Kingston to appear, Huffman 1989, Steriade 1989). The second statement encodes the fact that in the realization of the feature Nasal, a certain asymmetry is observed whereby [+nasal] effects are more pervasive than [-nasal] effects. In her proposed model of phonetic implementation of Nasal, Huffman (1989) encodes this asymmetry directly in terms of the nature of targets. As will be discussed in §4.7, although Huffman's proposal is an attractive one, it is not adequate to account for the broader range of patterns under investigation in the present study. Huffman appeals to values for both continuancy and nasality in her model of implementation, but in quite a different way than proposed here.

Sample derivations for /t-n/ and /t \checkmark / are presented in (14).

(14) Derivations

Phonological Output:	a.	t n	b.	t \checkmark
		-N +N		-N +N
Phonetic Implementation:				
Target Assignment:				
Priority Statements:		[+nasal] > [-nasal]		[-cont] > [+cont]
Interpolation:				

We start in these derivations at the output of the phonology. In (14a), each segment is translated into a target. In this case, the nasal consonant has priority over the stop. Since both are [-continuant], (13b) ([+nasal] > [-nasal]) determines the priority, resulting in quite a steady amplitude of flow for most of each segment duration, with the transition from oral to nasal during the stop release of the /t/. The derivation in (14b) is similar, except that here the stop has priority over the nasal vowel ([-cont] > [+cont]) and the transition occurs during the beginning of the vowel.

The assumption that feature specifications are mapped to targets with inherent duration, taken together with these two simple statements of transition priorities, accounts well for the cases considered so far.

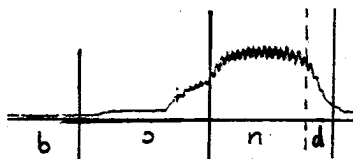
There are questions raised by the proposed priority statements: are such priority statements universal and do they generalize to the implementation of other features? Although the priority statement in (13b) [+nasal] > [-nasal] is pervasive cross-linguistically, it seems unlikely to be universal. There are cases of orality spreading, often described phonologically, but which may well, on closer inspection, turn out to be phonetic (see Anderson 1976). If certain aspects of these systems are phonetic, these would be cases where [-nasal] > [+nasal]. Whether these specific statements play a role in the implementation of other features is an empirical question. If this proposal is on the right track, it is predicted that such statements should play a role and one would expect that there would be a limited number of such statements.

4.4.4. Finer details: the turning points in vowels

Before turning to other cases, we consider some additional details of the realization of an oral vowel followed by a [+nasal] specification. As observed above, in the case of a vowel followed by a [+nasal] specification, a sharp turning point occurs late in the vowel. In the VN case we looked at, the turning point was very late; whereas in the VV̄ it was slightly earlier. As it turns out, there are some systematic differences in the finer details of the locations of the turning points, in terms of our analysis, the starting point and duration of the transition. Examples are presented in (15), with the relevant forms from above repeated.

(15) Examples of oral vowels preceding a [+nasal] segment

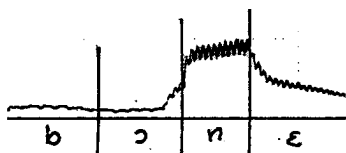
a. *bonne* /bɔn/ 'good' (f.) [F-D 2]



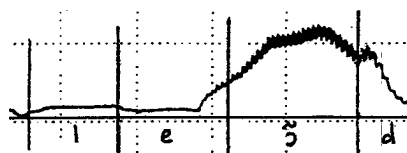
b. *beau nez* /bo#ne/ 'pretty nose' [F-D 5]



c. *bonnet* /bɔne/ 'bonnet' [F-D 5]

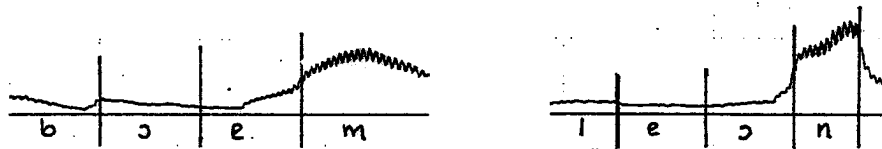


d. *Léon* /leɔ̃/ 'Leon' [F-D 2]

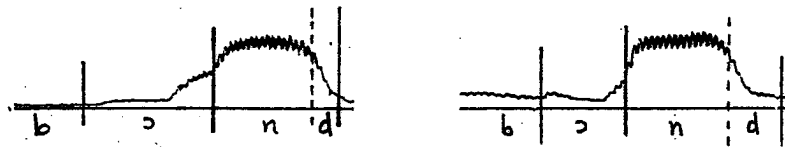


In all cases when a vowel is followed by a [+nasal] segment, either a consonant (15a, b, & c) or a vowel (15d), the transition is during the oral vowel. Yet there is some range as to how early in the vowel the onset of nasalization may occur. It is earlier in (15a) than in (15b) or (15c). Note that the word boundary in (15b) does not appear to affect the location of the turning point, as this case is not significantly different from (15c). There are a few structural and suprasegmental differences between these forms. First these cases differ in syllable structure, with the oral vowel and following nasal consonant tautosyllabic in (15a) but heterosyllabic in (15b & c). Second the stress patterns are different: in (15a) the oral vowel in question is stressed, whereas in (15b & c) the oral vowel is not stressed, rather primary stress falls in both cases on the final vowel of the word or phrase, following the nasal consonant. Additionally, (15a), but not (15b or c) is monosyllabic. To help sort out the source of this difference of turning point location, representative flow traces for two near minimal pairs are presented (16).

- (16) a. *Bohême* /bœém/ 'Bohemia' [F-D 4] b. *Léonore* /leɔnór/ 'Leonora' [F-D 3]



- c. *bonne (deux)* /bón/ 'good' (f.) [F-D 2] d. *bonne dette (deux)* /bɔndét/ 'good debt' [F-D 4]



In (16a & b), we observe an earlier onset of nasalization in the form /bœém/ than /leɔnór/. These two forms are very similar, except for the additional syllable in /leɔnór/, yet the onset of nasalization is earlier in /bœém/. The /e/ in /bœém/ is stressed, whereas in /leɔnór/ it is not; and the oral vowel and nasal consonant are tautosyllabic in /bœém/, but not in /leɔnór/. These forms differ in stress and syllable affiliation; so one or both of these must be, at least in part, responsible for the observed difference. In (16c), *bonne (deux)* /bón/ 'good' (f.) and (16d) *bonne dette (deux)* /bɔndét/ 'good debt', we again observe a difference, with an earlier onset of nasalization in (16c). In this case, the forms differ in number of syllables and stress, but not syllable affiliation of the VN sequence. Assuming a single principal factor is responsible for these timing differences, stress must be the most important factor, since a stress difference is shared by all of these cases. (Note that as stress assignment in French is predictable, barring emphatic or contrastive stress, it is not possible to construct minimal pairs.)

There are also some segmental effects of the preceding consonant, observed in the monosyllabic forms. The onset of nasalization is later if the preceding consonant is a stop. It may be that the turning point needs to remain later in the cases with a preceding stop, in order to better maintain the contrast between a nasal and oral vowel (since as observed above, the onset of nasalization in a nasal vowel is later following a stop than other classes of segments.) This effect

was quite marked for F-D, but not for F-F. As this was not systematically observed for the two speakers, I will not pursue this issue here.

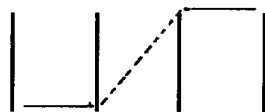
In all cases, we observe that the onset of nasalization is relatively late in the vowel preceding a [+nasal] specification, consistent with the proposed analysis. But these slight differences in realization of the turning point also need to be accounted for in a complete analysis. It must be the case that there are phonetic rules which, in effect, stretch or expand the duration of the transition at the end of the stressed vowel, to account for the fact that, in some of these cases, nasality infringes on more than just 20-30ms of the vowel. I will not develop these finer phonetic rules here as a much more systematic study of the various possible conditioning factors would be required.

4.4.5. (-N) ØN +N patterns

The classes of segments considered until this point were assumed to be specified for the feature Nasal at the output of the phonology. We turn now to the realization of glides and liquids preceding a [+nasal] segment. Based on our study of Sundanese, there is no reason to assume that these [+continuant] segments are specified for Nasal leaving the phonology. We predict, therefore, that we should see a transition throughout the duration of the segment, as observed in cases involving glides and /l/ in Sundanese, as schematized in (17).

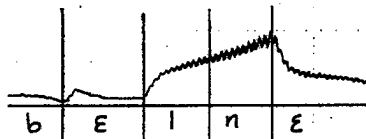
(17)	Phonological	x	x	x
	Output:			
		-N		+N

Phonetic Implementation:

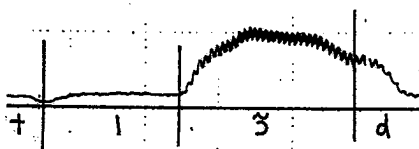


Consider now the representative flow traces presented in (18) for lN, lV, and G∇.

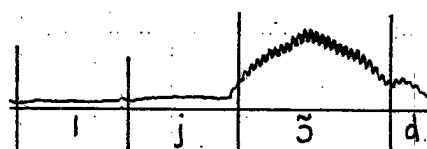
(18) a. lN *belle Nel* /bel#nɛl/ 'pretty Nell' [F-D 1]



b. lV *long* /lɔ̃/ 'long' [F-D 4]



c. G∇ *lion* /ljɔ̃/ 'lion' [F-D 1]



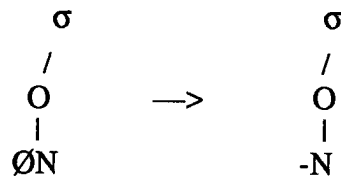
In /bɛlnɛl/ in (18a), we observe the onset of nasalization at the beginning of the liquid and a steady increase in nasal flow throughout the liquid. This is as predicted, if the segment is unspecified for Nasal and there is interpolation throughout. (Note that there continues to be an increase in nasal flow throughout the nasal consonant as well, similar to the increase in flow observed in other nasal consonants.) There are no examples of glide-nasal consonant sequences in the data set, so it is not known whether a transition throughout would be observed as in the /l-n/ case, but this would be predicted. (A form such as *paille neuve* /paj nœv/ 'new straw' would be informative and should be considered in a future study.)

As seen in (18b & c), the patterns with lV̄ and GV̄ are quite different: a glide or /l/ followed by a nasal vowel is oral throughout except for a very local transition at the end of the segment. The onset of flow starts right at or just before the onset of the vowel, with a slight peak at the onset of the nasal vowel in some cases, due perhaps to changes in oral pressure. This pattern is similar to the SV̄ case, except that the transition is earlier in the cases involving a [+continuant]. This difference in timing between SV̄ and [+continuant]V̄ cases is also noted by Al-Bamerni (1983) and can be seen in the data of Brichler-Labaeye (1970).

The behavior of [+continuant] consonants can, thus, be quite different. In the case of (18a), nasal flow increases throughout, whereas in the case of (18b & c), the /l/ or glide remains oral for most of its duration. The most salient structural difference between these two cases is the syllable position of the consonant: it is syllable initial when preceding a nasal vowel, but syllable final when preceding the nasal consonant.

It has been observed that consonants are more fully specified syllable initially than syllable finally, e.g. the place of articulation of a nasal and the voicing of an obstruent are often determined by context when in syllable final position (e.g. Harris 1984). Thus it might be the case that a [+continuant] consonant is [-nasal] syllable initially, but unspecified syllable finally. There is no reason to assume that /l/ and glides are underlyingly specified for Nasal, since Nasal is not contrastive for this class of segments. The differences in specification can be accounted for by a phonological rule, the Syllable Onset Default Rule, presented in (19):

(19) Syllable Onset Default Rule



A consonant unspecified for the feature Nasal in syllable onset position receives a default [-nasal] specification. The different realization of /l/ in /lʒ/ and /bɛlnɛl/ would result from the applicability or non-applicability, respectively, of this rule. If we assume that the glide in /lʒ/ is also in the onset (as suggested above in §4.2.2), we would also expect the glide to be [-nasal], compatible with the observation that a glide in this environment is oral for most of its duration. (The situation with glides is actually somewhat more complex, as will be discussed in §4.5.4.) Since these segments in syllable initial position are [-nasal] at the output of the phonology, we

expect them to look like the $S\check{V}$ cases. The only observed difference between the former and latter cases is the location of the transition. In the $S\check{V}$ cases the transition is during the vowel, whereas in the $L\check{V}$ cases, it at the end of the consonant. This difference is predicted by the transition priority statements proposed above. In the $S\check{V}$ cases, S has priority ($[-cont] > [+cont]$), whereas in the $L\check{V}$ and $G\check{V}$ cases, it is the nasal vowel that has priority (both are $[+continuant]$, so $[+nasal] > [-nasal]$). Sample derivations for $/b\epsilon l n \epsilon l/$ and $/t l \zeta/$ are presented in (20).

(20) Derivations

Input:	a.	$b \ \underline{\epsilon l n} \ \epsilon l$	b.	$t \ l \ \zeta$
		$\begin{array}{c} \quad \\ -N \ +N \end{array}$		$\begin{array}{c} \quad \\ -N \ +N \end{array}$
Syllabification:		$\begin{array}{c} \sigma \quad \sigma \\ \quad / \\ R \quad O \\ /\ \backslash \quad \\ \epsilon \ l \ n \\ \quad \\ -N \ +N \end{array}$		$\begin{array}{c} \sigma \quad \sigma \\ \backslash \quad / \backslash \\ R \quad O \ R \\ \quad \quad \\ t \ l \ \zeta \\ \quad \\ -N \quad +N \end{array}$
Syllable Onset Default Rule:		—		$\begin{array}{c} \sigma \quad \sigma \\ \backslash \quad / \backslash \\ R \quad O \ R \\ \quad \quad \\ t \ l \ \zeta \\ \quad \\ -N \ -N \ +N \end{array}$
		$\begin{array}{c} \sigma \quad \sigma \\ / \quad \rightarrow \quad / \\ O \quad \quad O \\ \quad \quad \\ \emptyset N \quad -N \end{array}$		
Phonological Output:		$\begin{array}{c} \epsilon \ l \ \$ \ n \\ \quad \\ -N \ +N \end{array}$		$\begin{array}{c} t \ \$ \ l \ \zeta \\ \quad \quad \\ -N \ -N \ +N \end{array}$
Phonetic Implementation:				
Target Assignment:				
Priority Statements:		NA		$[+nasal] > [-nasal]$
Interpolation:				

In (20a), the nasal vowel is specified, but the $/l/$ is unspecified for the feature Nasal. Syllabification takes place, but the Syllable Onset Default Rule is not applicable, since the

unspecified segment is not in the syllable onset. Each Nasal specification receives a target. No transition priority statements are applicable, since there are no adjacent Nasal specifications. I assume that in such cases the specified segments dominate the transitions. Interpolation between the [-nasal] of the preceding oral vowel and [+nasal] specification of the following nasal consonant results in a smooth cline-like transition throughout the /l/. In (20b), Syllabification takes place. Since the /l/ is in syllable onset position, the Syllable Onset Default Rule applies, assigning the syllable initial /l/ a [-nasal] specification. The output of the phonology is as shown. Each Nasal specification receives a target. No priority statements are relevant between the /t/ and /l/ since they have like targets; the nasal vowel has dominance over the /l/ (both are [+cont], so [+nasal] > [-nasal]) with the transition from [-nasal] to [+nasal] occurring at the end of the /l/.

To summarize, we have observed that the anticipatory cases are compatible with the proposed analysis in which feature specifications are mapped to targets lasting most of the duration of a segment, with priority statements accounting for the location of the local transitions. Additionally, it was argued that syllable initial glides and /l/ are specified for the feature Nasal leaving the phonology by a default fill-in rule, but that the syllable final [+continuant] consonants remain unspecified.

4.5. Rules with contexts

Consider now the expected output of a [+nasal] segment followed by a [-nasal] segment (a [-continuant] consonant, a vowel, or a glide or /l/ in syllable initial position), as schematized in (21):

(21) Phonological Output:	<table border="0" style="margin-left: auto; margin-right: auto;"> <tr> <td style="text-align: center;">x</td> <td style="text-align: center;">x</td> </tr> <tr> <td style="text-align: center;"> </td> <td style="text-align: center;"> </td> </tr> <tr> <td style="text-align: center;">+N</td> <td style="text-align: center;">-N</td> </tr> </table>	x	x			+N	-N
x	x						
+N	-N						
Phonetic Implementation:							

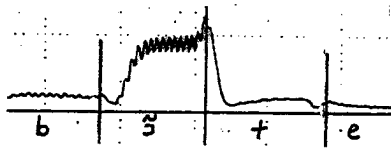
The nasal segment should be nasal for most of its duration and the oral segment should be oral for most of its duration. The proposed priority statements predict that the nasal segment, consonant or vowel, should have priority over the transition, except in the case of ∇S .

4.5.1. Modifying priorities

Consider first the ∇T and NT patterns exemplified in (22).

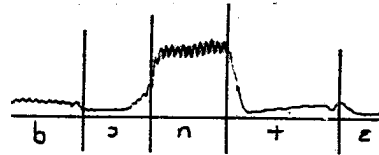
(22)a. ∇T

bonté /bɔ̃te/ 'goodness'
[F-D 3]



b. NT

bonne tête /bɔ̃n#tɛt/ 'good head'
[F-D 5]



When a /t/ is preceded by a nasal vowel, as exemplified in (22a), a rapid drop in nasal flow occurs during the first 20-30 ms of the stop. In some cases, this is preceded by a spike in nasal flow, simultaneous with the oral closure. This spike is probably due, in part, to increased nasal flow because of the oral closure, and, in part, to overall increase in airflow. As exemplified in (22b), in the case of a /t/ preceded by a nasal consonant, nasal flow is quite constant until voicing stops, at which point a rapid transition of 20-35ms (measured from the end of voicing) occurs.

The observed patterns involving /t/ are overall as predicted by the proposed analysis. The nasal and oral segments are nasal and oral for most of their duration respectively, as expected. The nature of the local transitions, however, are not completely in fitting with the proposed priority statements. The transition in the NT case is as expected: the transition from nasal to oral takes place at the beginning of the /t/ ([+nasal] > [-nasal]). But the transition between the ∇ and /t/ is not as predicted by the statement [-continuant] > [+continuant]. Following this statement, we would expect the transition to be during the vowel, not the stop. Yet instead, this case fits with the pattern of [+nasal] > [-nasal]. It seems to be the case that it is only the release of a [-continuant] segment, not the onset of closure, that has to be respected (has to remain oral). This is in keeping with the observed special status of stop releases (see Huffman 1989). Priority statement (13a) needs to be modified. Unlike priority statement (13b) which is context free, (13a) must be context sensitive. Both statements are presented in (23).

(23) a. [-continuant] > [+continuant] iff [-cont] / ____ [+cont]

b. [+nasal] > [-nasal]

where a. has precedence over b.

The modified priority statements account for the observed transitions.

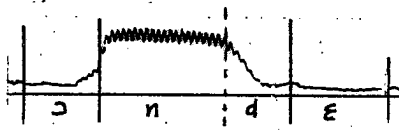
4.5.2. Lack of phonological specification after a [+nasal] specification.

The other cases of a [-nasal] segment following a [+nasal] segment, ND, ∇D , NV, ∇V , NL, ∇L , NG, ∇G , are expected to show the same general pattern. In the case of a following stop or vowel, these are expected to be specified as [-nasal] leaving the phonology due to phonological contrast, while in the case of the glides and liquids, these receive their [-nasal] specification by the Syllable Onset Default Rule. But in both cases, the oral segments are expected to be specified as [-nasal] by some point in the phonology. Yet looking at the representative flow traces for these

patterns, presented in (24), we observe a strikingly different pattern. (NG and ∇G are not included. We return to these patterns below.)

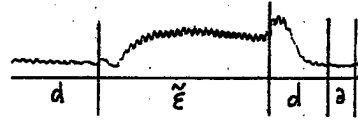
(24) a. ND

bonne dette /bɔ̃n#dɛt/ 'good debt' [F-D 3]



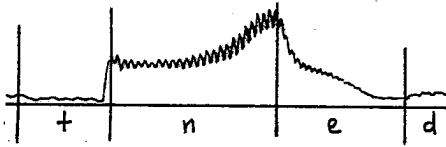
b. ∇D

dinde /dɛ̃d/ 'turkey' (f.) [F-D 4]



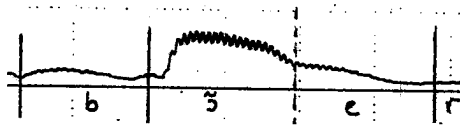
c. NV

nez /ne/ 'nose' [F-D 5]



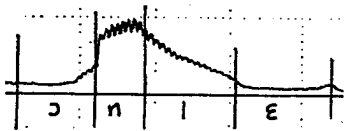
d. ∇V

bon héros /bɔ̃#ɛro/ 'good hero' [F-D 1]



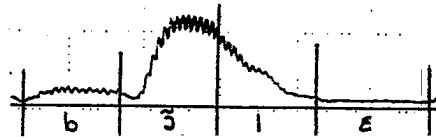
e. Nl

bonne lettre /bɔ̃n#lɛtʁ/ 'good letter' [F-D 3]



f. ∇l

bon lait /bɔ̃#lɛ/ 'good milk' [F-D 1]



As exemplified in (24a & b), when a [+nasal] segment precedes a voiced stop, then for much of the duration of what would be expected to be the voiced stop nasal airflow is present. It is only by the time of the stop release that the nasality is eliminated. When the preceding segment is a nasal consonant (shown in (24a)), no marked change in flow is observed. This is as expected, since there is no change in oral closure. In this case no independent means of segmentation is possible, but the portion with significant nasalization takes up well over half of the combined duration of the two segments. This pattern is not a result of the fact that the nasal-stop sequence is homorganic, as a similar pattern is observed for forms of /m-d/ sequences. When the preceding segment is a nasal vowel (exemplified in (24b)), in some cases, an increase in flow is observed at the point of oral closure, presumed to be due to the oral closure resulting in greater airflow through the nose. This is less obvious following /ʒ/, where, as discussed above, oral flow is minimal. The level of flow tends to be maintained for the first third to half of the stop. (This duration might be an absolute one, rather than a proportion of the duration of the segment. More systematic manipulation of the time domain would be needed to determine whether this were the case.) When nasalization continues into the period of oral closure, the effect is of a brief epenthetic nasal consonant. (Similar effects of nasalization on a following voiced stop are observed by Malécot and

Metz (1972), in what they term progressive nasal assimilation. But this may be a separate phonological process, since it occurs in a much more specific environment and affects, in some cases, voiceless stops as well as voiced ones.)

As exemplified in (24c), a vowel following a nasal consonant is significantly nasalized, decreasing throughout the vowel. Characteristically, a rapid drop occurs in the first 20-30 ms, corresponding to the release of the closure and rise in oral airflow; beyond this point, flow slowly decreases throughout the duration of the segment. In VV cases (24d), no such rapid drop occurs, but a similar transition is observed.

When /l/ is preceded by a [+nasal] segment, either a nasal consonant or a nasal vowel (shown in (24e & f respectively)), it is very amenable to nasalization. When the following segment is oral, nasalization is transitional throughout the /l/, but by the beginning of the following vowel no more nasalization is observed; it is not cline-like into the vowel.

In all of the cases in (24), full nasalization of the nasal consonant or vowel occurs and the transition from nasal to oral takes place during the following segment. But unlike the transitions between two segments both specified for the feature Nasal observed so far, which were rapid, in these cases the transitions are slow, lasting most of the duration of the segment. The vowel or consonant following a [+nasal] segment is significantly nasalized, with decreasing flow throughout the segment, resulting in negligible flow by the end of the segment. In each case, appreciably more nasal flow is present during the following "oral" segment than predicted.

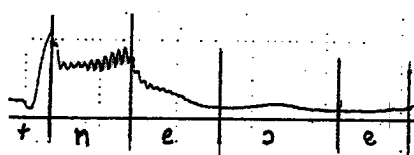
This pattern is not symmetrical with the anticipatory pattern discussed above in §4.4. In the anticipatory cases, onset of nasal flow was late in the oral segment preceding a [+nasal] segment, whereas in the carryover cases just presented, the offset of nasal flow is not at the beginning of an oral segment following a [+nasal] segment, but rather toward the end, with a fairly smooth transition throughout. Although the shapes of the clines differ somewhat depending on what the segment is, similar patterns are observed in each case. (A similar asymmetry was observed by Benguerel 1974 and Benguerel et al. 1977a, where in a VNV sequence, it was noted that the second vowel showed more velum lowering than the first one.)

We have seen that a segment which immediately follows a nasal is amenable to nasalization for most of its duration, yet there is little if any effect on a subsequent segment. This is quite clear in the case of NVV sequences, where the first vowel is nasalized in a transitional way for most of its duration, but the following vowel is not. Two such cases are exemplified in (25):

(25) NVV cases

a. *Noël* /nɔɛl/ 'Noel' [F-D 3]

b. *néo-hébridais* /neɔɛbridɛ/ 'of the
'New Hebrides' [F-D 3]



In both cases, the first vowel is nasalized in a transitional manner throughout its duration, but no significant nasal flow is observed by the onset of the second vowel. (The pattern observed in

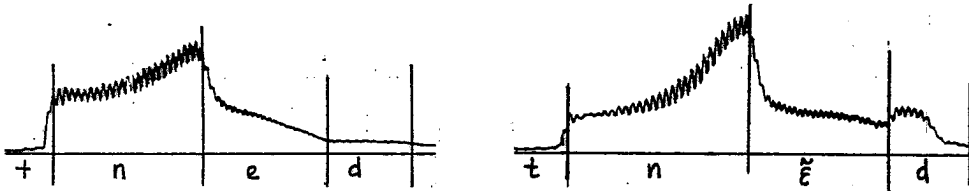
this case for Speaker F-F is somewhat different, as slight flow is, in some cases, observed on a subsequent vowel. In general Speaker F-F has somewhat less sharp transitions than Speaker F-D.)

It is worth comparing an NV case with a N \bar{V} case, since the oral nasal contrast for vowels is maintained in this environment in French. Examples as shown in (26):

(26) NV vs. N \bar{V}

a. *nez (deux)* /ne#d/ 'nose'
[F-D 3]

b. *nain (deux)* /nɛ#d/ 'dwarf'
[F-D 3]



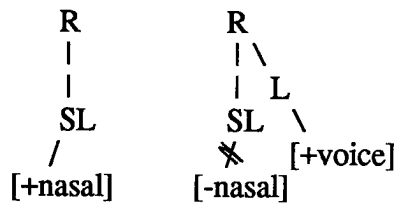
The two forms in this case look quite similar. Both show a comparable drop in flow after the nasal consonant (due to the release of the oral closure). The oral vowel (26a) and nasal vowel (26b) are differentiated only by the flat character of the flow on the nasal vowel and the more cline-like flow on the oral vowel. This is a rather subtle difference for a phonemic contrast. But they also differ noticeably as far as the degree of flow on the following stop, in this case the /d/ of the frame sentence. Perceptually this may be as salient (or more salient) a cue to the contrast. Again we see that in effect only one segment following a [+nasal] specification is affected.

Note that the anticipatory cases, where the patterns for nasal and oral vowels are quite distinct, pose no serious problem for perception. But in the carryover cases, it is an interesting question how the speaker judges. Benguerel and Lafargue (1981) address some general questions of perception of nasalization in French, but do not specifically consider the two carryover patterns.

These carryover cases look very much like the glides and /l/ in Sundanese following a segment specified as [+nasal], where the glide or /l/ showed transitional flow throughout its duration. It was argued that this cline-like pattern is due to the fact that these segments are unspecified for the feature Nasal at the output of the phonology and the cline-like pattern of flow is a result of interpolation from a preceding [+nasal] specification to a following [-nasal] specification. If French works the same way, then the phonetic evidence suggests that at the output of the phonology, voiced stops, vowels, and [+continuant] consonants following a [+nasal] specification are unspecified for the feature Nasal. Yet it was argued above that at some point in the phonology, these segments are specified as [-nasal]: the voiced stops and vowels due to phonological contrast and the glides and /l/ due to the Syllable Onset Default Rule. These specifications were supported by the observed patterns of anticipatory nasalization, where no such extended transitions were observed.

To account for both the anticipatory and carryover patterns, it must be the case the [-nasal] feature specifications are deleted after a [+nasal] specification. I propose a [-Nasal] Deletion Rule, as stated in (27):

(27) [-Nasal] Deletion



A [-nasal] feature specification is deleted when following a [+nasal] specification. Since this deletion does not affect /t/s which are [-nasal], I assume that this rule only applies to [+voice] segments. On this view, syllable initial [+continuant] consonants receive a [-nasal] specification by the Syllable Onset Default Rule and then later lose this specification by the Nasal Feature Deletion Rule, which does not refer to syllable structure. An alternative approach would be to assume that the Syllable Onset Default Rule is less general than stated above and does not apply when the target of the rule follows a [+nasal] specification. In the absence of clear evidence to decide between these two approaches, for the sake of concreteness, I assume that all syllable initial [+continuant] consonants receive specifications which are later lost in some cases.

The rule of [-Nasal] Deletion removes a phonological feature specification and thus lets phonetic implementation determine the observed pattern. Note that this mechanism is distinct from phonological spreading, as will be seen below in §4.5.4.

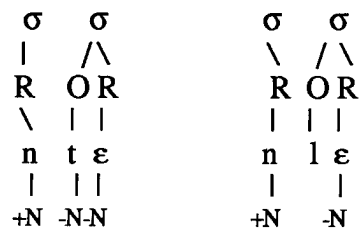
Sample derivations are presented in (28).

(28) Derivations

Input:

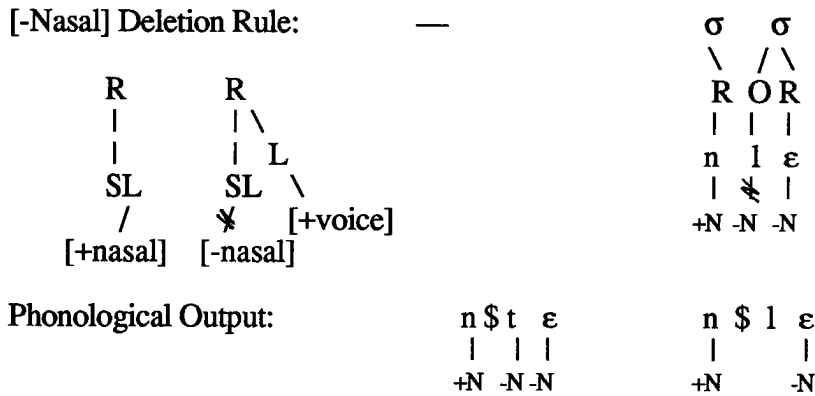


Syllabification:

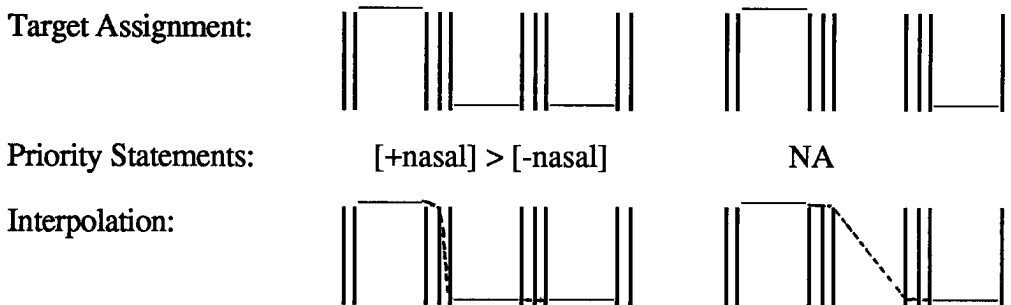


Syllable Onset Default Rule: —





Phonetic Implementation:



In (28a), the derivation is very similar to those presented in the anticipatory cases. The phonological output is as shown. Both the nasal consonant and following /t/ receive a target for most of their duration. The nasal consonant has priority over the transition, following the priority statement [+nasal] > [-nasal]. In (27b), the /l/ starts out as unspecified, being a [+continuant] consonant. But since it is in syllable onset position, it receives a [-nasal] specification by the Syllable Onset Default Rule, which is subsequently lost due to the [-Nasal] Deletion Rule. It is, therefore, unspecified at the output of the phonology and does not receive a target of its own. Rather it receives a transitional amount of nasalization throughout its duration, due to interpolation between the preceding [+nasal] specification and following [-nasal] specification. No priority statements are relevant, since there are no adjacent unlike Nasal specifications. The derivation of a voiced stop or oral vowel following a [+nasal] specification would be parallel.

The rule of [-Nasal] Deletion accounts for the observed asymmetry between anticipatory and carryover nasalization in French, encoding this difference as a phonological one. We can ask whether this asymmetry might not be the result of a mechanical effect. The velum is often described as being a "sluggish" articulator (Hudgins & Stetson 1937, Ohala 1971, 1975) and it has been argued that it rises more slowly than it lowers. This might be a physiologically motivated tendency, but clearly the velum can move quite quickly when necessary, e.g. in a NT sequence, where we observed a rapid transition and no asymmetry with the anticipatory case. Thus the effect can not be purely mechanical and therefore must be part of the linguistic grammar.

The proposed solution accounts for the asymmetry in terms of production. Yet it might be the case that what is at the heart of the asymmetry is perception. In articulatory terms, at times greater carryover nasalization is observed than anticipatory nasalization (cf. Al-Bamerni 1983), yet

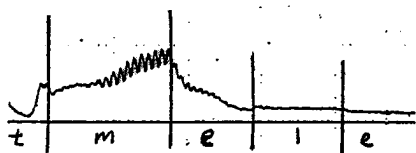
it is most characteristically anticipatory nasalization that becomes phonologized. It seems quite likely that preceding a nasal segment, a very small amount of nasalization is perceptually salient, whereas following a nasal segment, a significant amount of nasalization is perceptually discounted due to the preceding context. Yet even if the asymmetry is explainable in perceptual terms, we still must account for the asymmetry in the phonetic realization of such patterns.

4.5.3. Interpolation over two unspecified segments

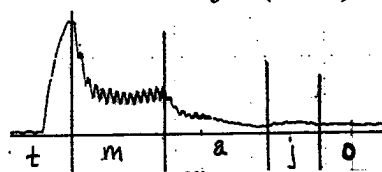
In cases of a [+continuant] consonant following a nasal consonant-vowel sequence, the proposed analysis predicts that the observed pattern of nasalization will differ depending on the syllabification of the consonant. The Syllable Onset Default Rule predicts that there should be a cline-like transition throughout both the vowel and following glide or /l/ if the consonant is in the syllable rime, since the consonant would remain unspecified in these cases. But when these consonants are in syllable-initial position, both should be specified as [-nasal], blocking any nasalization past the preceding vowel. Examples of two such minimally contrasting pairs are presented in (29):

(29) NV\$R vs. NVR\$

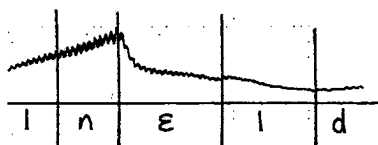
a. NV\$I *mêler* /mele/ 'to mix' [F-D 2]



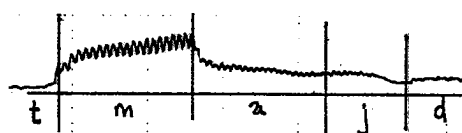
b. NV\$G *maillot* /majo/ '(swim) suit' [F-D 4]



c. NVI\$ (*belle*) *Nel* /nɛl/ 'Nell' [F-D 1]



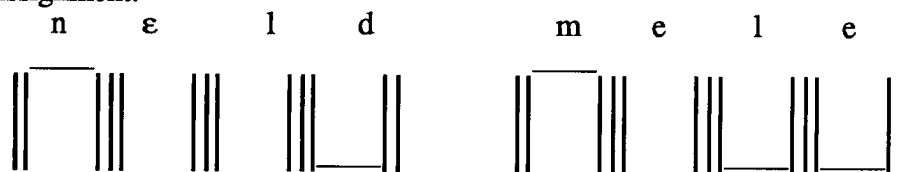
d. NVG\$ *maille* /maj/ 'stitch' [F-D 5]



In (29a & b), the glide and /l/ are syllable initial and therefore are expected to be specified as [-nasal]. In both cases the offset of nasal flow is toward the end of the preceding vowel. In (29c & d), the glide and /l/ are in coda position in the rime and are therefore expected to remain unspecified at the output of the phonology. In these cases then, the vowel immediately following the nasal consonant is unspecified due to the [-Nasal] Deletion Rule and the following glide or /l/ is also unspecified. We expect to see a cline-like transition throughout both of these segments. The flow traces in these cases seem to show a longer cline than in (29a & b) without a clear turning point at the end of the vowel, consistent with the predicted difference. But the amplitude of flow is quite small and approaches the level of noise in the data. No strong conclusions can be drawn without collecting additional data, but the observed patterns are suggestive and appear to support the predicted difference. (Here again is a case where the patterns observed for Speaker F-F are slightly different, with slightly longer distance flow nasalization observed even in the NV\$R cases. But these results are difficult to interpret as there was more leakage in the data for Speaker F-F.)

Phonetic Implementation:

Target Assignment:



Priority Statements:

NA

NA

Interpolation:



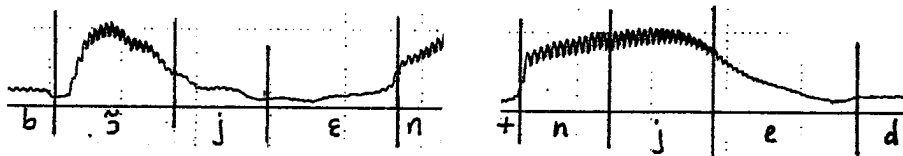
In (30a), both the vowel and the following /l/ are unspecified at the output of the phonology, the vowel due to the application of the [-Nasal] Deletion Rule and the /l/ unspecified throughout the derivation. In the phonetic implementation of this form, we, therefore, expect a cline throughout both of these segments. On the other hand, in (30b) only the vowel is unspecified (again due to the application of the [-Nasal] Deletion Rule); since the /l/ receives a [-nasal] specification by the Syllable Onset Default Rule, we, therefore, expect a cline only through the duration of the vowel, not into the following /l/.

4.5.4. The realization of glides following a [+nasal] specification

In discussing the carryover cases, we left aside the behavior of glides. A priori, we would expect glides to behave like /l/'s following a [+nasal] specification. Yet the observed pattern is different from that for /l/ and depends on whether the glide is preceded by a nasal vowel or a nasal consonant, as shown in the representative flow traces in (31).

(31) a. *bon yen* /bɔ̃#jɛn/ 'good yen'
[F-D 2]

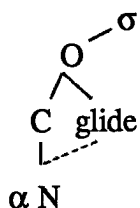
b. *nier* /nje/ 'deny'
[F-D 5]



As exemplified in (31a), the glide following a nasal vowel in a form such as /bɔ̃jɛn/ shows a cline-like transition with basically no nasal flow by the end of the glide, similar to the pattern observed above for /l/. But we observe a clear difference between the realization of the glide in this case and in the case of a glide following a nasal consonant, such as /nje/ in (31b). As shown in (31b), the flow on a glide in this cases is not cline-like throughout the segment; rather the glide is fully nasalized throughout its duration. Unlike other voiced segments, which appear to be unspecified for Nasal following a [+nasal] specification, a glide following a nasal consonant appears to be specified as [+nasal].

This fits in with a more general observation. We saw above that a glide between a syllable initial consonant and following vowel was fully oral if the preceding consonant was oral, such as in the case of /ljʃ/. The generalization that emerges is that a glide in the environment between a syllable initial consonant and a following vowel has the same value for the feature Nasal as the preceding consonant. If the preceding consonant is nasal, the glide is nasalized, if it is oral the glide is oral. As noted above, in such cases the glide is assumed to be part of the onset. This nasal assimilation appears to be a phonological one, in that its effects are categorial. In effect, onsets agree in nasality. I propose a phonological spreading rule to account for this:

(32) Onset Assimilation Rule



A glide following a syllable initial consonant agrees in nasality with that consonant, due to a spreading of the Nasal feature value from the preceding segment. This accounts for the orality following an oral segment and nasality following a nasal segment. This rule must be ordered after the Syllable Onset Default Rule to account for such forms as /ljʃ/, where both the liquid and glide are observed to be oral.

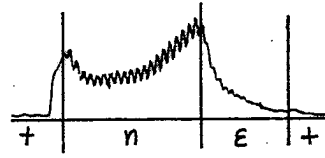
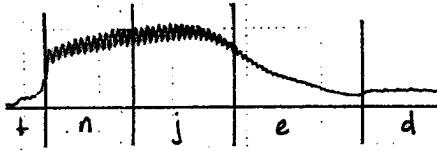
I have stated the rule as referring only to glides in this position, but one wonders if this might not be a more general characteristic of onsets, such that other initial clusters, such as /tr/, /bl/, etc., would also be expected to agree in nasality. There are no such forms in the data set to confirm or disprove this possibility.

The fact that a glide is either fully oral or fully nasal in this environment, depending on the nasality of the preceding consonant, provides some evidence for the view that the glide does indeed have a phonological specification for the feature Nasal. Additional evidence that the glide has a nasal specification is the pattern of flow observed on the following vowel. It was argued above that an oral vowel immediately following a [+nasal] specification loses its [-nasal] specification, but that a vowel following an intervening segment is not affected, as seen in the NVV cases presented above in (25). If the glide is specified as [+nasal] in these cases, an immediately following vowel should show a cline-like pattern of flow. Precisely this pattern is observed as can be seen in (33) where NGV is compared with NV and NLV.

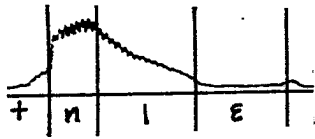
(33) Comparison of NV, NGV, and NIV

a. NGV *nier* /nje/ 'deny' [F-D 5]

b. NV *net* /net/ 'clean' [F-D 3]



c. NIV *bonne lettre* /bɔn#letr/ 'good letter' [F-D 3]



The pattern of flow on the vowel in the NGV case (33a) is very similar to that seen in the NV case (33b) and very different from that seen in the NIV case (33c). The significant transitional flow on the vowel in the NGV cases supports the conclusion that it is adjacent to a [+nasal] specification, and thus that the glides in this environment are indeed specified as [+nasal]. Here we see the difference in the phonetic output of a segment specified as [+nasal] following a nasal consonant (actually a shared specification with the nasal consonant), NG; and an unspecified segment following a nasal consonant, NV.

The difference between the \checkmark G case and the NG case follows from the application of the Onset Assimilation Rule in the latter but not the former case as illustrated in the following derivations:

(34) Derivations

Input:

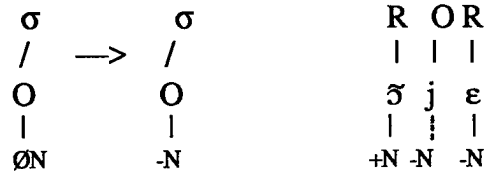
a. (b) \checkmark # j e (n) b. n j e # d

 | | | | |
 +N -N +N -N -N

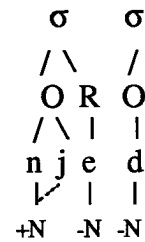
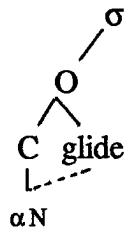
Syllabification:

σ	σ	σ	σ
	/ \	/ \	/
R	OR	O	R O
		/ \	
\checkmark	j e	n j e d	
+N	-N	+N -N -N	

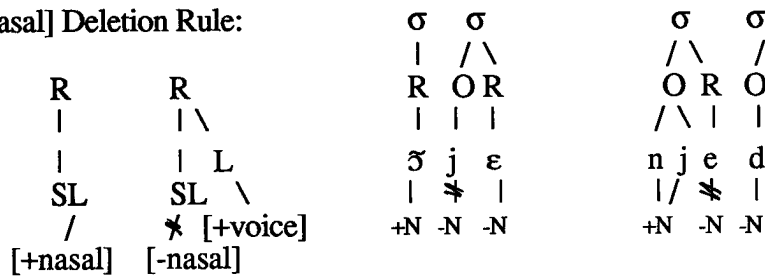
Syllable Onset Default Rule:



Onset Assimilation Rule:



[-Nasal] Deletion Rule:

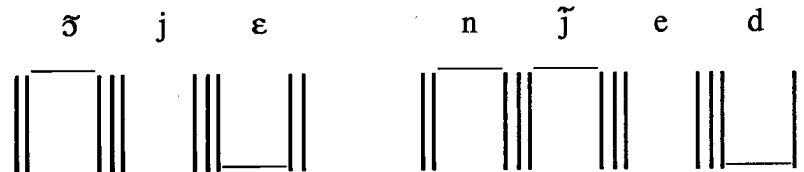


Phonological Output:



Phonetic Implementation:

Target Assignment:



Priority Statements: NA

NA

Interpolation:



In (34a), the glide receives a [-nasal] specification by the Syllable Onset Default Rule, but this is later deleted by the [-Nasal] Deletion Rule. At the output of the phonology, the glide is unspecified, receiving a cline-like pattern of nasalization through interpolation between the

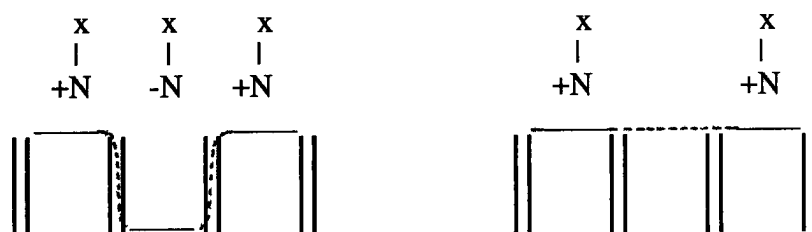
preceding [+nasal] specification and following [-nasal] specification. Note that the Syllable Onset Default Rule is crucially ordered before the [-Nasal] Deletion Rule. In (34b), the Syllable Onset Default Rule is not applicable. The Onset Assimilation Rule applies, spreading the [+nasal] specification of the preceding nasal consonant to the glide. When the [-Nasal] Deletion Rule applies, it is the [-nasal] specification of the following vowel which is deleted, since it is immediately adjacent to the [+nasal] specification. The glide surfaces as fully nasalized and the following vowel show a cline-like pattern of nasalization due to phonetic implementation.

We have now considered both anticipatory and carryover cases. In all cases, nasal segments, both consonants and vowels, are significantly nasalized throughout most of their duration. They also have priority over transitions, except in the case of $S\check{V}$, where the stop has priority. In other words, nasal segments are realized as significantly nasalized independent of the context. The only oral segments that are also realized in a context independent manner are voiceless stops, which we observed were oral for most of their duration, whether preceded by or followed by nasal segments. The other cases, voiced oral segments, are, to varying degrees, affected by context. In the cases of vowels and voiced stops, we observed an asymmetry in the realization of nasalization in the anticipatory and carryover cases, with significantly more carryover than anticipatory nasalization. This difference was accounted for by the proposed rule of [-Nasal] Deletion. The significant contextual effects, such as in the case of IN and in the case of voiced oral segments following a nasal segment, were argued to be due to a lack of a nasal specification for those segments, either due to underspecification maintained throughout the phonology or the application of the [-Nasal] Deletion Rule.

4.6. Phonetic constraints

The case that will most fully determine the degree of contextual effects on oral segments is when these segments occur between two [+nasal] segments, the most restrictive environment. In this case, anything that the oral segment imposes must be inherent to that segment. The expected outputs for this pattern, based on the proposed analysis, are schematized in (35).

(35) a. intervening segment specified b. intervening segment unspecified



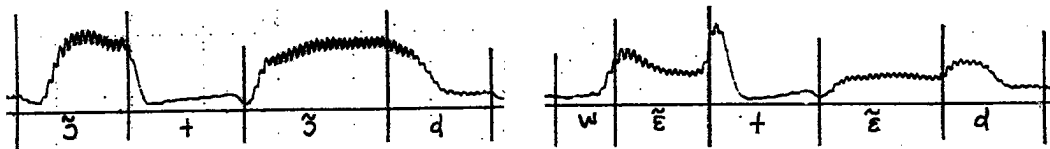
As schematized in (35a), if the intervening oral segment is specified as [-nasal] leaving the phonology, we expect that it should be oral for most of its duration; this is the pattern predicted for /t/. On other hand, if the intervening oral segment is unspecified for Nasal leaving the phonology, as argued to be the case for the voiced oral segments following a [+nasal] specification (excluding a glide following a nasal consonant), we expect to see nasalization straight through the unspecified segment due to interpolation between the preceding and following [+nasal] feature specifications, as schematized in (35b). In what follows we consider the actual realization of these cases.

4.6.1. +N -N +N and +N ØN +N patterns

We consider first voiceless stops and then turn to the voiced segments (voiced stops, vowels and continuant consonants), where we will see that interesting differences emerge. We will observe that some of these segments do maintain some degree of orality and it is argued that these effects are due to phonetic requirements or constraints on these particular segments.

As noted above, the realization of /t/ is closely constrained on both of its edges. This should also be true in the case of /t/ between two [+nasal] segments, since /t/, being voiceless, retains its [-nasal] specification. This is exemplified in two forms in (36).

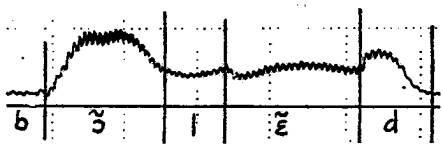
(36) a. *bon thon* /bɔ̃#tɔ̃/ 'good tuna' [F-D 4] b. *lointain* /lwɛ̃tɛ̃/ 'far' [F-D 5]



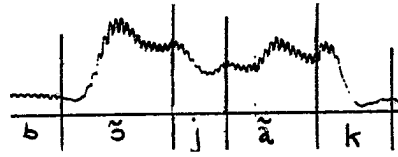
In these cases, the /t/ is indeed oral for most of its duration. There appears to be an oral target throughout the duration of the segment. We see a rapid transition at the beginning of the segment and no nasal flow until the release of the stop. These transitions are comparable to what was seen for the anticipatory and carryover cases taken separately and can be accounted for by the proposed priority statements. This is similar to the case of the [+nasal] segments, in that its realization is context independent.

Consider now the realization of voiced oral segments between two [+nasal] specifications. Voiced stops, oral vowels and /l/ are all predicted to be unspecified in this environment, even if syllable initial, and therefore are expected to show a significant amplitude of nasal flow through interpolation. Glides are also expected to be realized with a significant amplitude of nasal flow, but, in some cases, for a different reason: if the preceding [+nasal] is a consonant, glides are expected to be [+nasal] through the spreading of the preceding [+nasal] specification through the Onset Assimilation Rule. Representative examples for these patterns are presented in (37).

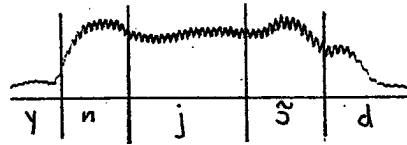
(37) a. *bon lin* /bɔ̃lɛ/ 'good flax'
[F-D 3]



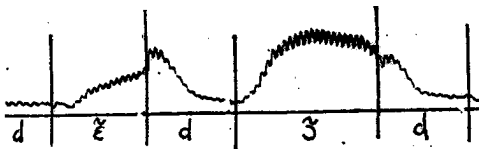
b.i. *bon Yankee* /bɔ̃jãki/ 'good Yankee'
[F-D 5]



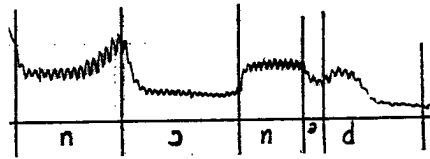
ii. *union* /ynjɔ̃/ 'union' [F-D 4]



c. *dindon* /dɛ̃dɔ̃/ 'turkey' [F-D 5]



d. *nonne* /nɔ̃n/ 'nun' [F-D 5]



When /l/ occurs between two [+nasal] segments (exemplified in (37a)), it is nasalized straight through, consistent with the view that it has no target of its own. The greater flow on the preceding nasal vowel is due to the low oral flow for /ɔ̃/. The /l/ and /ɛ/ both have higher oral flow than /ɔ̃/, thus relatively less nasal flow.

In (37bi & ii), we see two examples of glides in this environment: in the former case following a nasal vowel and in the latter case, following a nasal consonant. In both cases, we observe significant nasalization straight through. In the former case, as with the /l/ case, it is argued to be due to the fact that the segment is unspecified at the output of the phonology. The observed pattern in the latter case is very similar, with the glide fully nasalized; yet in this case, argued to be due to a [+nasal] specification. The fact that there is little difference in these cases suggests that the nature of interpolation in these cases is linear. (What difference is observed is presumably due to differences in the oral impedance of the neighboring context.)

In (37c & d), we observe that the cases with /d/ and non-nasal vowels are quite different from those of the glides and /l/. In each case, less nasalization is observed than predicted by the proposed analysis. In (37c), the /d/ is not nasalized straight through, but rather the release is clearly oral. Even though it was argued above that voiced stops following [+nasal] specifications are unspecified leaving the phonology, some sort of phonetic requirement of orality still obtains. It is not the case that we wrongly predicted the removal of the [-nasal] specification, as the observed target is quite different from the one expected were the /d/ specified as [-nasal] leaving the phonology. We will pursue this issue below.

In the case with the intervening vowel (37d), here again less flow is observed than predicted by our analysis. We see a clear plateau for most of the vowel, below the level expected if there were straight interpolation. Yet at no point does the level of flow approach zero flow. (The oral impedance is important in this case, in determining that there is actually less nasal flow than expected. Rough calculations of flow ratios were carried out for these forms and it was concluded that the levels were indeed lower than would be expected.) It again does not appear to be the case that we wrongly predicted the removal of a phonological [-nasal] specification, since the observed pattern is not consistent with a [-nasal] specification (i.e. this case is quite different from the pattern observed for /t/). Here again it appears to be the case that the phonetic component imposes its own requirements.

4.6.2. The nature of phonetic requirements

The observed patterns for voiced stops and vowels between two [+nasal] specifications suggest that even when phonologically unspecified, a segment may nevertheless have phonetic requirements on its realization. For example, this might be the case for [s] in English, which is phonetically [+high], although this does not play a role in the phonology (see Keating 1988b). We turn now to the nature of these phonetic requirements.

4.6.2.1. Phonetic requirements of stops

Both phonologically and phonetically voiceless stops are oral, that is they are assumed to be [-nasal] at the output of the phonology and they are phonetically realized as oral throughout most of their duration independent of context. The behavior of voiced stops is less straightforward. They are assumed to be oral and are realized as oral throughout their duration, except when following a [+nasal] specification, in which case there is a transitional amount of flow ending in an oral release, no matter whether the following segment is oral or nasal. The beginning of a voiced stop may be contextually determined, but the release of a voiced stop is oral, independent of context. Oral stops share the fact that the release is oral (not a surprising constraint considering that without an oral release the contrast between an oral voiced stop and a nasal consonant would be marginal or non-existent, see Ohala 1975). Yet voiceless stops seem to have an oral target for most of their duration; whereas voiced stops minimally have an oral target only at their release, with quite a bit of latitude about the nasality of the first part. The different phonetic requirements are schematized in (38):

(38) Phonetic requirements of voiced and voiceless stops



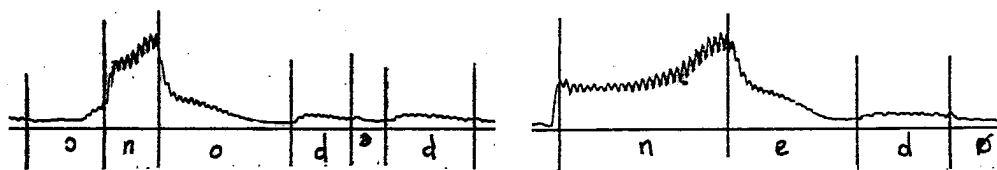
At least phonetically, voiced stops have oral releases, whereas voiceless stops must be oral for most of their duration.

It was argued above that voiced stops lose their phonological [-nasal] specification after a [+nasal] specification. It was assumed that this rule applied to voiced stops, but not voiceless ones which were observed to have an oral target for most of their duration. It might well be the case that voiceless stops also lose their [-nasal] specification. It might be the case that the [-Nasal] Deletion rule is a more general one, but that the phonetic requirements of voiceless stops are such that the observed output is the same under the two views – the phonetic requirements would undo the effect of the [-Nasal] Deletion Rule. In the absence of data to decide between these two views, I assume that it is only voiced segments that are affected by [-Nasal] Deletion, as stated above.

We have assumed that /d/ and /t/ have the same kind of target when specified as [-nasal] in the phonology; yet one might at this point raise the question of whether the same phonological feature specification might be translated into a different type of target, depending on the segment or class of segments it is associated with in a particular case. In the cases studied, we have only observed voiced stops to have a restriction on their right edge. Since the preceding segment in a case like /dʒ/ was a /t/, the orality of the beginning of the voiced stop may be due to context. It might be argued that a [-nasal] feature specification is realized as a target with an inherent duration in the case of /t/, but as a target of a single point at the end of the segment in the case of /d/.

One might assume that somewhere in the mapping from features to targets, there are statements which say how a feature specification is interpreted in a particular situation or for a particular class of segments. Such a state of affairs requires manipulating timing in terms of both inherent duration of targets and relative placement. This is potentially descriptively adequate, but perturbing in terms of excessive power. Such a state of affairs would be theoretically unattractive, since this would mean that the realization of a particular feature specification is different for certain classes of segments. But more to the point, in this particular case, such a solution is empirically inadequate. The left edge of a voiced stop, not immediately following a [+nasal] specification is oral, and not just determined by context. This can be seen in a voiced stop following a NV sequence. Whether in syllable final or syllable initial position, such a stop is oral by the beginning of the segment, similar to the pattern observed with voiceless stops, as exemplified in (39).

(39)a. *bonne ode* /bɔn#od/ 'good ode' [F-D 3] b. *nez (deux)* /ne#d/ 'nose' [F-D 5]



In both (39a & b), we observe no significant nasalization at the beginning of the voiced stop. This supports the conclusion that, when phonologically specified, /d/ has an oral target similar to that observed for /t/. Voiced stops differ from [+continuant] consonants in that their specification is not dependent on syllable structure. This is because voiced stops are specified for Nasal due to contrast with nasal consonants; whereas the [+continuant] consonants which surface as specified for Nasal in French are due to phonological rules sensitive to syllable structure.

We might argue that the [-nasal] specification of the /d/, but not the /t/, is somehow weakened, but not deleted after a nasal segment. We would then expect to observe the same

pattern, for example, for vowels following a [+nasal] specification, which also seem to be "weakened". Yet the observed pattern for NVN is quite different from that observed for $\nabla D \nabla$, and we would be forced to conclude that the notion of weakening would have to be different for different classes of segments.

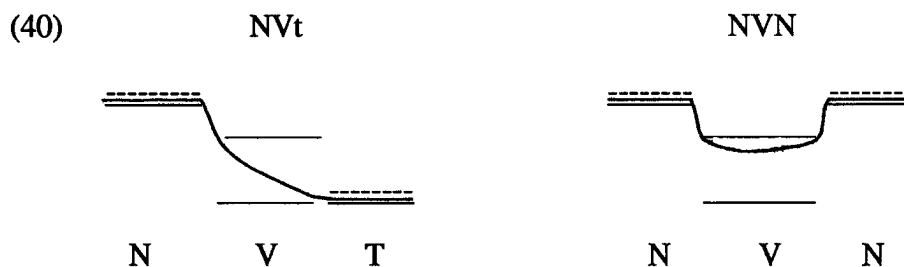
The most straightforward account appears to be that the phonological specification of a voiced stop is deleted after a [+nasal] specification, but that even in the absence of phonological feature specification, the phonetics may nevertheless impose certain requirements. How these constraints are imposed is discussed below in §4.6.3.

4.6.2.2. Phonetic requirements of vowels

We now return to the case of oral vowels between [+nasal] specifications. We saw above that there was more flow than expected if these segments had [-nasal] specifications, but less than expected if there was no target. When specified as [-nasal], a vowel is realized as oral for most of its duration, but when this specification is lost and the vowel has no phonological specification, the phonetics again imposes certain phonetic requirements. It seems to be the case that there is some kind of range or ceiling for nasality for non-nasal vowels (i.e. for vowels not specifically marked as [+nasal]).

This situation is very reminiscent of the ceiling of nasality on vowels in English. Although vowels are nasalized in certain contexts, it is observed that the velum raises slightly during a vowel in a NVN sequences (see Kent et al. 1974). Keating (1987, 1988a) has proposed an account for the English facts within a window theory, in which segments are assumed to be realized within certain phonetic ranges. Different segments have different possible ranges or windows. Keating argues that in order to account for velum position in English, nasal consonants would have narrow, low-velum-position windows (in our terms high flow), oral consonants would have narrow, high-velum-position windows (that is low flow) and vowels would have wide windows. This accounts nicely for the fact that there is a wider range of realization of nasality on vowels in English than on either nasal or oral consonants.

I suggest that the ceiling on nasal flow for non-nasal vowels after a nasal consonant in French be accounted for in a similar fashion. A non-nasal vowel has a fairly wide range of possible phonetic values (in contrast to a nasal vowel, with a narrow window similar to a nasal consonant). But this range of values only surfaces in the event that the [-nasal] specification of the vowel is deleted; otherwise, if specified as [-nasal], these vowels are realized as oral for most of their duration. Windows for both the NV and NVN cases are schematized in (40). I assume that both [n] and [t] have very narrow windows.



The nature of the phonetic requirements is different from those observed for voiced stops, but a close parallel exists in that the phonetic requirements surface only when these segments are unspecified leaving the phonology. In the case of glides and /l/ unspecified at the output of the phonology, there was seen to be interpolation straight through, although these cases might also be interpreted as having wide windows; perhaps we have not observed examples that show what the actual limits are. Following Keating's window theory, phonetic (but not phonological) underspecification is a gradient property. Segments will be underspecified to the degree that their windows are wide.

4.6.3. An analysis of phonetic constraints

We now need to consider how these phonetic requirements or constraints fit into our proposed analysis. So far, we assumed that if a segment is specified for the feature Nasal at the output of the phonology, it is mapped to a target for most of its duration. If a segment is unspecified, it is assumed to receive quantitative levels of nasalization through interpolation. What we have now seen is that independent of a phonological specification, the phonetics may impose requirements. I propose that at the point of target assignment, phonetic constraints also come into play. These only play a significant role when the particular segment is unspecified for the feature Nasal, since the targets assigned by phonological feature specification are as strong as, or stronger than, the phonetic requirements.

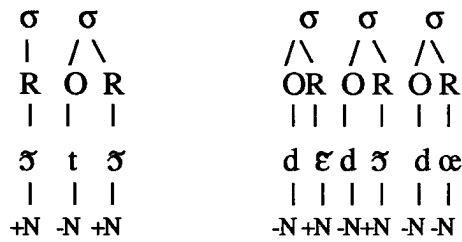
I believe that these phonetic constraints follow from articulatory (aerodynamic) or perceptual requirements. (Although this does not mean that they are necessarily universal: in cases where there are language specific differences, there might be language specific constraints or the differences might be parameterized). In many cases these constraints will not have a chance to surface, when even stronger requirements are imposed by a phonological specification. To the degree that phonology is "natural" there will be a close correspondence between these two sources of information. To the degree that phonology is an abstract system, there will be differences. This integration of feature specifications and phonetic constraints encodes the fact that the connection between phonology and phonetics may be direct at times and indirect at other times. We might view these constraints as an instantiation of Ohala's (1975) observation that "The extent to which oral sounds may become nasalized via assimilation depends on their acoustic and articulatory requirements." (p. 300).

Sample derivations illustrating the role of these phonetic constraints are presented in (41) and (42). In (41) derivations for *bon thon* /bɔ̃tɔ̃/ 'good tuna' and *dindon (deux)* /dɛ̃dɔ̃#dœ/ 'turkey (twice)' are presented.

(41) Derivations

Input:	a. (b) ɔ̃ # t ɔ̃	b. d ɛ̃ d ɔ̃ # d œ
	+N -N +N	-N +N -N +N -N -N

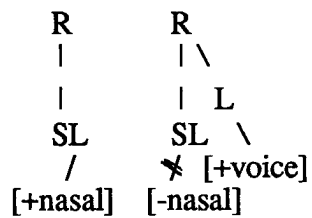
Syllabification:



Syllable Onset Default Rule: —

Onset Assimilation Rule: —

[-Nasal] Deletion Rule: —

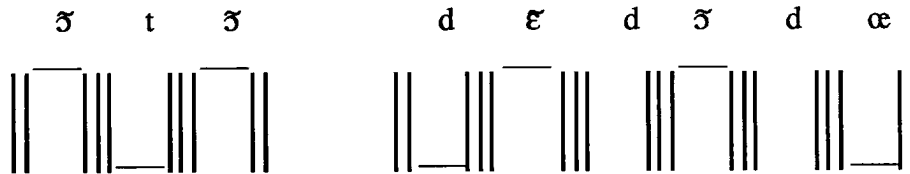


Phonological Output:

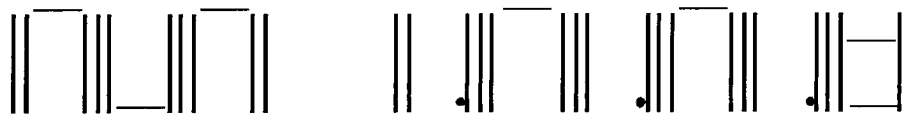


Phonetic Implementation:

Target Assignment:



Phonetic Constraints:



Priority Statements:

[+nasal] > [-nasal]

[-cont] > [+cont]

Interpolation:



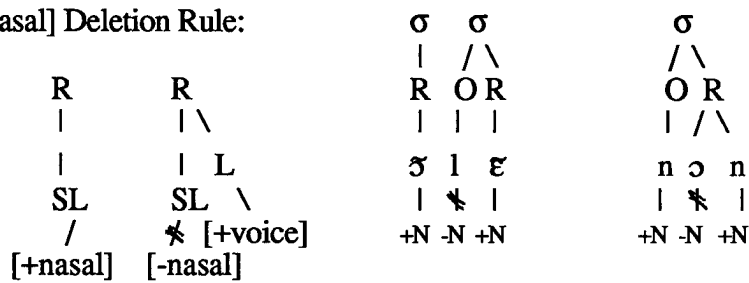
In (41a), each of the segments is specified for the feature Nasal at the output of the phonology and therefore each receives a target. By this hypothesis, it is a phonetic requirement of both nasal consonants and voiceless oral stops that they be nasal or oral respectively for most of their duration. But in this case the phonetic requirements are isomorphic with the targets assigned due to phonological specification. In both transitions, [+nasal] has precedence over [-nasal], resulting in transitions at the beginning and end of the /t/. The phonetic output as shown is quite similar to the actual flow traces of this form, exemplified above in (36a). In (41b), we have examples of the realization of /d/ in three different contexts. Phonologically all of the segments are specified due to contrast, but the second and third /d/'s both lose their [-nasal] specifications by the [-Nasal] Deletion Rule. Thus only the first /d/ is specified at the output of the phonology. The specified segments receive targets. In this case the phonetic requirements of the nasal vowels are isomorphic with the assigned targets. The oral vowel is phonetically constrained by a window, but is realized in this case as fully oral due to the target assigned by its [-nasal] specification. Each of the /d/'s has an oral release as its phonetic requirement. In the case of the first /d/, this requirement is masked by the full oral target due to the /d/'s [-nasal] specification, but this requirement comes into play in the realization of both the second and third /d/. In both of these cases interpolation is constrained by this phonetic requirement. This is most obvious in the case of the second /d/. Again the phonetic output closely approximates the actual flow traces, exemplified above in (37c).

Sample derivations of *bon lin* /bɔ̃lɛ/ 'good flax' and *nonne* /nɔ̃n/ 'nun' are presented in (42).

(42) Derivations

Input:	a. (b) ʒ # l ɛ	b. n ɔ̃ n
	+N +N	+N -N +N
Syllabification:	σ σ	σ
	/ \	/ \
	R OR	O R
		/ \
	ʒ l ɛ	n ɔ̃ n
	+N +N	+N -N +N
Syllable Onset Default Rule:	σ σ	—
	/ \	
	R OR	
	ʒ l ɛ	
	+N -N +N	
Onset Assimilation Rule:	σ σ	—
	/ \	
	R OR	
	ʒ l ɛ	
	+N -N +N	

[-Nasal] Deletion Rule:



Phonological Output:



Phonetic Implementation:

Target Assignment:



Phonetic Constraints:



Priority Statements:

NA

NA




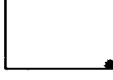



Interpolation:



In (42a), /l/ occurs between two nasal vowels. First /l/ receives a [-nasal] specification due to the Syllable Onset Default Rule; this is later lost due to the [-Nasal] Deletion Rule. At the output of the phonology /l/ is unspecified. The nasal vowels receive targets, which due to their [+nasal] specification are isomorphic with the phonetic requirements. The /l/ has no phonetic requirements and so we observe straight interpolation through the /l/ (cf. the example flow trace in (37a)). As shown in (42b), the derivation for a vowel between two nasal consonants is similar. The vowel is unspecified leaving the phonology, due to the [-Nasal] Deletion Rule. The feature specifications of the nasal consonants are mapped to targets, again isomorphic with the phonetic requirements. Here the vowel has a phonetic requirement of its own. There is a ceiling on how nasalized it may be and this ceiling constrains the pattern of interpolation between the nasal consonants (cf. the example flow trace in (37d)). In these derivations, we see that the feature specifications and phonetic targets taken together account for the observed phonetic realizations of these patterns.

Our observations of the phonetic realization of each class of segments discussed above, along with the proposed phonological representation at the output of the phonology, are summarized in (43):

(43) Summary of phonological specifications and phonetic requirements

	phonological spec	phonetic requirements
Nasal consonants	[+nasal]	
Nasal vowels	[+nasal]	
Voiceless stops	[-nasal]	
Voiced stops	[-nasal] except / +N ____ [Ønasal] / +N ____	
Vowels	[-nasal] except / +N ____ [Ønasal] / +N ____	
/l/	[Ønasal] except syll. initially [-nasal] syllable initially when not preceded by a [+nasal] segment	
Glides	[Ønasal] except α N/ \$C__	

At the output of the phonology, all nasal segments, both consonants and vowels, are [+nasal]. These [+nasal] segments must be nasal or nasalized in a significant way for most of their duration. We assume that [-continuant] oral segments and oral vowels are specified for the feature Nasal at the output of the phonology due to contrast with [+nasal] specifications and the observed phonetic patterns, except following a [+nasal] specification. We observed that voiceless stops are oral throughout, consistently in the phonology and the phonetics. This might generally be the requirement of non-sonorant voiceless segments or it may be a combination of constraints on voiceless segments and stops. In these cases, the phonetic constraints are isomorphic with the results of phonological specification.

Although we assume that /d/ is [-nasal] (being specified as a [-continuant] segment), its phonetic requirement (more generally that of voiced stops) is only that it have an oral release. To be a well-formed /d/, this is the minimal requirement. A possible aerodynamic explanation is that, in order to produce the needed flow for the release, sufficient pressure build up is required. (Huffman 1989 discusses this issue.)

Vowels, like voiced stops, are [-nasal] except when following a [+nasal] specification, in which case they are phonologically unspecified. But phonetically a ceiling limits their degree of nasalization, represented as a fairly wide range of possible values.

Glides and /l/ are unspecified leaving the phonology except for certain contexts, as determined by syllable structure. When unspecified leaving the phonology, this class of segments

appears to have no phonetic constraints. (This is similar to the observed patterns for /h/ and glottal stop as well as the glides and /l/ in Sundanese.)

4.7. Implications of the analysis

In this section, we discuss the implications of the data and proposed analysis. In §4.7.1, we consider the role of syllable structure in an adequate account of these data; in §4.7.2, we compare the observations here with previous data on nasalization in French; and in §4.7.3, we discuss Huffman's (1989) proposed model of phonetic implementation of the feature Nasal.

4.7.1. The role of syllable structure

We observed above that carryover effects of nasalization, although quite significant on a segment immediately following a [+nasal] specification, are local. Following the view that [l] and glides are generally unspecified and that non-nasal vowels have wide windows, we would predict that a sequence of such segments following a [+nasal] specification would result in cline-like effects over a longer distance. Yet with the possible exception of /nɛl/ and /maj/ discussed above, this is not what we observe. Rather the effects are localized to the immediately following segment.

In these cases, the next following segment is in another syllable, thus the cline is limited to within the syllable. Does this mean that a syllable-bounding principle needs to be encoded into the phonetic realization of these cases? Not necessarily, as there are independent aspects which when taken together account for this observation. All syllable initial consonants receive a phonological specification, either due to contrast or following the Syllable Onset Default Rule. We have also argued that non-nasal vowels receive [-nasal] specifications. These cases taken together account for the fact that carryover effects of nasalization are blocked at the syllable boundary when not immediately adjacent to a [+nasal] specification. Syllable structure does indeed play a role in the phonetic implementation of the feature Nasal in French, but it is a result of phonological representations and does not need to be directly encoded in the phonetics. (However, there are other more subtle phonetic effects of syllable structure in French, such as the shape of the flow curve, which do need to be accounted for within the phonetics.)

4.7.2. Previous data in the literature

Although the previous phonetic literature on nasalization in French is quite extensive, few of the studies address the issue of primary interest here: the mapping from phonology to phonetics for the feature Nasal. Most of the studies that describe contextual nasalization do not propose a specific linguistic model of accounting for it. In a few studies, a Henke type look-ahead model is concluded to be inadequate (see Benguerel 1974 and Benguerel 1977a & b), but no real alternative models are proposed. Benguerel (1977a) and Benguerel and Lafargue (1981), noting the similarity of oral vowels in a nasal context and nasal vowels, make the interesting suggestion that there might be some kind of time integration performed by the listener to distinguish between contrastive nasalization and contextual nasalization.

Nevertheless, the previous literature presents data which are of interest. Some of the data were collected in studies specifically focused on the velum (Delattre 1965, 1968, Benguerel 1974,

Benguerel 1977a & b, Zerling 1984). Some of these previous studies, although interesting, are difficult to interpret as they do not present change over time. Others studies are part of broader phonetic studies of French, most notably the x-ray (cineradiographic) studies of Brichler-Labaeye (1970), Rochette (1973), and Botherel et al. (1986), which present a wide range of phonological patterns of French. (There are numerous other articles which mention patterns of nasalization French, but where only limited data are presented.)

Overall, these studies confirm the observations made in the present study, which is encouraging, since most of these data were collected using other methodologies. Most generally, it is observed that both nasal consonants and nasal vowels are nasal for most or all of their duration (cf. Brichler-Labaeye 1970, Rochette 1973, Benguerel 1977a, among others). It has also been observed that there are contextual effects of nasalization on segments adjacent to a nasal segment (Delattre 1965, Benguerel 1974, Benguerel et al. 1977a, Al-Bamerni 1983, Zerling 1984). In these data, patterns similar to those noted above are seen, where there are slight anticipatory effects of nasalization preceding a nasal segment, as well as effects following a nasal segment. Although these observations are basically limited to the effects of a nasal consonant on either a preceding or following vowel, consideration is not given to the wider range of contexts under investigation in the present study.

The timing of such effects is based on consideration of the point of velum opening or closing. Data from fiberoptic, x-ray, and electromyographic studies show that velum lowering or raising, or muscle activity related to such movement, starts well before, and continues considerably after, actual velum opening or closure. Thus from a more physical point of view, coarticulation, in the sense of muscle activity, is much more extensive. But as noted in Chapter 2, it is higher level events, actual opening and closure, that are the focus of the present investigation, as it is believed that these correspond more closely to linguistically relevant events, since only at the point of opening or closing is there a concomitant perceptual cue of change.

The x-ray studies of Brichler-Labaeye (1970), Rochette (1973) and Botherel et al. (1986) are of particular interest, since although the patterns of nasalization were not the primary focus of investigation, in all three cases sequences of frames are presented for particular segments and sequences of segments which allow consideration of velum lowering/raising and opening/closing over time. Only single tokens are presented, but a wide range of patterns are included.

The data in Botherel et al. (1986) support the observations made here. In particular, both nasal consonants and nasal vowels have an open velum position for most or all of their duration; voiceless stops are seen to have the velum closed throughout most of their duration, whereas if a voiced stop follows a nasal vowel, the velum may remain open until close to its release. The patterns of contextual nasalization of vowels, both anticipatory and carryover, are also similar to those observed above, with anticipatory nasalization in a VN sequence starting about two thirds of the way through the vowel or later and carryover nasalization through much or all of the following vowel. None of the cases involving a liquid or glide that we might be interested in are presented, but there are several cases with a voiceless fricative (/s, f/) adjacent to a nasal segment, and in these cases the velum is observed to be closed for most of their duration, allowing slight nasalization at their onset. This supports the view that not just voiceless stops, but also voiceless segments more generally have phonetic requirements to be oral.

In Brichler-Labaeye (1970), extensive examples of both oral and nasal vowels are presented. The "oral" vowels are observed to have the velum closed throughout, with two systematic exceptions: (1) after a nasal consonant, where significant velum opening is observed; and (2) utterance finally, during the final few cineradiographic frames. I assume that this is due to the utterance final position. (We cannot see this with the present data set as all forms were collected in a frame sentence.) This could be accounted for with a low velum position, due to rest position. This would be the opposite of the high velum position observed as a speech readiness position. (There are no cases of a vowel preceding a nasal consonant in the tracings presented.) The nasal vowels are as expected, with velum lowering occurring during the first frame or two.

In Rochette's (1973) cineradiographic study, the primary focus of investigation is consonant sequences. Systematic combinations of CC sequences are presented and discussed. Since all sequences occurred in running speech, such factors as stress, word boundaries, and syntactic phrasing may influence the realization of the patterns of movement. The most general result that emerges is that the transition between a nasal consonant and either a preceding or following oral consonant is always during the oral consonant. The duration of the transition is most typically 2.1 cs (one frame) or 4.2 cs (two frames), consistent with the expected durations of a transition. In the cases where we would predict longer distance effects (e.g. ND, NL, LN; glides are not included in Rochette's corpus), an open velum is observed for most of the duration of the consonant for at least some of the tokens. In the cases in which such effects are not observed, this may be due to syntactic phrasing or word boundary effects, since many of the consonant sequences occur across word boundaries. Rochette also discusses effects on amount of velum lowering due to the segment quality and that of adjacent segments, a point which cannot be fully evaluated in the present data set.

In conclusion, although most of these data were collected through other methodologies than in the present study, they are nevertheless consistent with the observations made above, lending additional support to the patterns observed here.

4.7.3. Discussion of Huffman (1989)

In this section we consider a recent proposal regarding implementation of the feature Nasal by Huffman (1989). We will see that her proposed model, based on nasal and oral airflow data from Yoruba and Akan (both languages which make a nasal-oral contrast for consonants and vowels), is compatible in many ways with the proposal presented here. But there are some substantive differences, which lead, in some cases, to wrong predictions for the data collected in the present study.

There are two basic components of Huffman's model.

(1) Velum movement is linked to particular "articulatory landmarks" (as noted by Huffman, an idea closely related to Kingston's (to appear) theory of articulatory binding). These landmarks are instantiated in a window type model (developed from Keating's 1988a model of windows, discussed above). Huffman proposes that the realization of temporal patterns of velum movement be accomplished through the association of temporal landmarks. Onset and release of consonant closure and peak of vowel gestures are such articulatory events. This is an important idea as it makes a specific and concrete proposal as to how time is incorporated in the realization of a

particular phonetic parameter or dimension. Her model has clear implications for how perception fits in, and offers a starting point as to how more than one such dimension might be integrated.

We see strong support for the relevance of onsets and offsets of consonantal closure in the present data and might well think of the more abstract notion of the beginning or end of a segment developed here as being, in fact, the type of landmarks described by Huffman. In effect, Huffman's proposal offers a phonetic explanation for our phonological expectation that a phonological feature target will be "stretched" throughout most of the duration of a segment when it is realized in real time.

(2) Huffman argues that [+nasal] segments have long targets, associated with two landmarks, whereas [-nasal] segments have a single landmark.

Huffman's proposal, adequate for the data under investigation in her study involving limited phonotactic patterns, is an interesting one. Yet when a fuller range of cases are considered, certain problems emerge.

There are two asymmetries encoded in Huffman's system: (1) [-continuant] consonants vs. vowels, where the former have two landmarks, but the latter only a single one, implemented through interpretation of Continuant values; (2) [+nasal] vs. [-nasal] segments, where the former associate with two landmarks and the latter only one. This predicts four basic patterns, as summarized in (44):

(44)	segment type	landmarks	association of landmarks to the feature Nasal
a.	Nasal consonants	2 (onset - offset)	onset and offset
b.	Nasal vowels	1 (middle)	preceding landmark to middle
c.	Oral stops	2 (onset - offset)	offset only
d.	Oral vowels	1 (middle)	middle only

Between landmarks which are not nasal, there is interpolation.

Let us consider each of these patterns in turn. Huffman observes that nasal consonants (44a) are nasal for all of their duration and captures this by assigning them two targets, at closure and release. We observe similarly in the present study that nasal consonants are nasal for their full duration. In the present analysis, such facts are argued to follow from a more general observation that feature specifications receive that specification for most of their duration.

Huffman argues that vowels have only a landmark in their middle rather than the two landmarks observed for [-continuant] segments. Nasal vowels (44b) are also observed to be nasalized for a significant duration, but they have one landmark in the middle, so the pattern of nasalization is argued to be due to nasalization starting at the point of the last landmark. This analysis is somewhat problematic for the data presented here. First, the nasal vowels are nasal for all or most of their duration and have similar effects on neighboring segments as nasal consonants. Second, Huffman's proposal makes a rather odd prediction, not borne out in the present data. In a

V̄V sequence, the nasalization should be most prominent from the middle of the oral vowel to the middle of nasal vowel, with decreasing nasalization starting in the middle of the nasal vowel. This is not the pattern observed in such cases, as shown above in (11d), where the most significant nasalization is throughout most of the duration of the nasal vowel itself. It seems that nasal vowels, like nasal consonants, have a nasal target for most of their duration. The location of landmarks for nasal vowels seems to relate to the segment edges, not the middle.

Huffman observes that oral stops may be nasalized at their onset, but must be oral by their release (44c). Her conclusions are based on voiced stops only and are similar to our observations of voiced stops in French. But her conclusions clearly do not generalize to voiceless stops, where orality is observed for most of the duration of the segment, even in the V̄tV̄ case (as see above in (36)). Under Huffman's approach, the voiceless stops, like the nasal ones, would necessarily have two targets, so the dichotomy between [+nasal] and [-nasal] is not as straightforward as it might have appeared. (Huffman (p.c.) acknowledges that Voice probably plays a role as well in the implementation of the feature Nasal and suggest that the [-voice] specification may, in effect, add a second target.)

Oral vowels, like nasal vowels, are argued to have a single oral target in their middle (44d). This predicts that vowels preceding a nasal consonant should be oral for the first half of their duration and have increasing nasalization for the second half, and that vowels following a nasal consonant should be the mirror image. These predictions clearly do not hold for the data observed for the speakers of French in the present study. First, the onset of nasalization, although somewhat variable (as discussed in §4.4.4), is typically later than the middle of the vowel, accounted for in our analysis by a full oral target followed by a transition dominated by the following nasal consonant. Thus here again a [-nasal] segment is seen to be oral for most of its duration. Second, the carryover nasalization is not the mirror image of the anticipatory pattern. Rather, nasalization continues in a cline-like manner for most of the duration of the vowel following a nasal consonant which is accounted for by the rule of [-Nasal] Deletion.

Huffman's data on oral vowels are a bit more ambiguous than predicted by her analysis. There are three issues that merit consideration, one of which Huffman herself discusses at length and offers an explanation for.

First, the onset of nasalization during /o/ before a nasal consonant in Yoruba and for one speaker of Akan does indeed start around the middle of the vowel (a bit earlier than such onsets are observed in the data for the speakers of French studied here), but the second speaker of Akan shows almost no nasalization till the very end of the vowel (cf. Figure 23, p. 85). Thus a range from the middle of the vowel to the end of the vowel occurs with respect to the location of the turning point for the onset of nasalization. There seems to be a greater range of turning points of onset of nasalization in both Huffman's and my data than accounted for directly in either of our analyses. This is an area that requires further study to better understand what influences these differences in specific turning points.

Second, as Huffman herself discusses, /a/ before a nasal consonant in Yoruba behaves quite differently from /o/, showing a very different pattern of nasalization. The /a/'s are typically nasalized from their onset, increasing throughout the duration of the segment (cf. Figure 24, p. 87). Huffman suggest that this might be accounted for by /a/ having a wider window than /o/. Yet this alone does not seem to be enough to account for these differences and weakens the argument

that there is indeed an oral target of any sort in the middle of oral vowels. The level of nasalization on these tokens is very similar to those seen on phonemic /ã/s in Yoruba (cf. Figure 21, p. 83), although more cline-like. This suggests that these vowels are actually unspecified for the feature Nasal. (Why they should pattern differently from /o/ is not clear.) This is clearly an issue that merits further investigation.

Finally, the carryover case, also predicted to have an oral target in the middle, looks like the mirror image of the Yoruba /a/ case, not the /o/ case, which would be expected as the more canonical pattern. Huffman explains this by the fact that the only carryover cases in her corpus involve /a/s and thus display the mirror image of the anticipatory pattern seen for /a/s. This does not lend additional support to the view that an oral target is present in the middle; and might actually be more consistent with the conclusion that a similar asymmetry occurs as observed in French, with more carryover nasalization than anticipatory.

If such an asymmetry exists, this raises broader questions with respect to an appropriate account of such asymmetries. In the data from French, such an asymmetry was seen for voiced "oral" segments, where they were oral for most of their duration before a nasal consonant, but were much more affected by a preceding nasal context, accounted for by the proposed phonological rule of [-Nasal] Deletion. Yet a similar asymmetry is observed for voiced stops and perhaps vowels in Huffman's data. Such asymmetries might thus be due to more general phonetic tendencies, rather than being the result of a language-specific phonological rule. This issue requires further cross-linguistic comparison to see how generally such asymmetries hold.

In order to capture the greater pervasiveness of [+nasal] specifications, Huffman proposes that [+nasal] segments receive two targets, whereas [-nasal] ones receive only one. Yet this solution is problematic in accounting for the inherent duration of oral targets in voiceless stops, voiced stops (except after a [+nasal specification]) and oral vowels. In the present study, such pervasive effects of nasality are observed as well, but these are captured by (1) interpolation through unspecified segments, and (2) priorities, whereby [+nasal] typically has dominance over transitions.

In conclusion, Huffman's proposal that implementation is related to articulatory events, and in particular that onset and release of consonant closures are such events, receives strong support from the present study, but some of the more specific aspects of the proposal, that vowels have a landmark only in their middle and that only [+nasal] specifications, but not [-nasal] ones, have targets with inherent duration, need to be expanded or modified to account for the present data.

4.8. Summary of the chapter

In this chapter, a detailed analysis was constructed to account for the implementation of the feature Nasal in French. A basic target-interpolation model was proposed, in which phonological specifications map to targets which consist of most of the duration of a segment. Transition priorities were proposed to account for the particular transitions observed between adjacent unlike feature specifications.

The proposed approach directly encodes the notion of plateaus being a result of the phonology (due to stretched out targets); while clines result from effects in the phonetics of local transitions or phonologically unspecified spans.

It was argued that the observed asymmetry in the effects of nasalization, whereby carryover effects are stronger than anticipatory ones, could be accounted for in a two-tiered approach where phonological specifications and phonetic constraints together account for the phonetic realization. Finally, it was concluded that the effects of syllable structure in the phonetics are not direct, but follow from the application of syllabically conditioned rules.

CHAPTER 5 ENGLISH

In this chapter, we consider data from English in light of the analyses for speakers of Sundanese and French, constructed in Chapters 3 and 4 respectively. In English, there is a nasal-oral contrast among the [-continuant] consonants, but no such contrast for vowels. English was chosen for comparison with French and Sundanese since it is therefore expected to have fewer restrictions or constraints on the realization of the feature Nasal. Such a comparison will allow us to address the question of which aspects of the analysis proposed for French are language specific and which are more general. Overall, we will see that the English data are quite compatible with the analysis proposed for French, with most observed differences due to differences in phonological representations. This leads to the conclusion that a theory in which phonological specifications are mapped to targets with inherent durations, and in which phonetic constraints come into play in the realization of the unspecified segments, is an appropriate one. Yet some unexpected results also emerge, involving effects from a series of allophonic rules, a phonetic restriction on long distance nasalization, and variability in the data.

The structure of the chapter is as follows. The English phoneme inventory and syllable structure are discussed in §5.1. Several phonological rules of English expected to affect the realization of the feature Nasal are described in §5.2. A description of the corpus is presented in §5.3. In §5.4-5.6, the English data are presented and analyzed. In §5.7, the role of variability is discussed. In §5.8 implications of the proposed analysis are considered in light of two recent papers on nasalization in English, Vaissière (1988) and Boyce et al. (1989). We conclude with a brief summary in §5.9.

5.1. The English phoneme inventory and syllable structure

5.1.1. The basic inventories

The consonant inventory of English is presented in (1).

(1) English consonants

	labial	interdent	alveolar	pal-alv	palatal	velar	glottal
stops							
voiceless	p		t			k	
voiced	b		d			g	
nasals	m		n			ŋ	
fricatives							
voiceless	f	θ	s			ʃ	
voiced	v	ð	z			ʒ	
affricates							
voiceless						tʃ	
voiced						dʒ	
liquids							
			l	r			
glides							
					j	w	h

The particular segments investigated in this study, taken as representative of their class, are enclosed in boxes. The contrast between nasal and non-nasal [-continuant] consonants is illustrated by minimal pairs such as *debt* /dɛt/ ~ *net* /nɛt/, *beat* /bit/ ~ *meat* /mit/, *rig* /rɪg/ ~ *ring* /rɪŋ/.

The vowel inventory of the dialect of English studied here is presented in (2):

(2) English vowels

	front		back
high	i		u
	ɪ		ʊ
mid	e		o
	ɛ	^	
low	æ		ɑ

No nasal vowels are present in the phonological inventory of English, although it has been argued that a surface contrast may occur between forms such as *cat* [kæt] ~ *can't* [kæ̃t]. If this is found to be a genuine surface contrast, it can be accounted for with a rule of nasalization and subsequent deletion of the nasal consonant, and does not argue for an underlying contrast for Nasal within the vowels in English.

5.1.2. Syllable structure in English

Generally, possible syllable structure, involving both onsets and codas, are more complex in English than in either French or Sundanese. But most of the additional possible complexity does not affect the types of patterns that we are interested in investigating. What is relevant to our discussion is the syllable affiliation of medial consonants and medial consonant clusters. A priori, we expect the following syllabification for such sequences: V\$CV, VC\$CV (unless the CC is a possible onset). Yet Kahn (1976) has shown that sometimes a consonant, such as the underlined ones, may actually have dual syllable membership, being simultaneously part of the coda of the preceding syllable as well as part of the onset of the following syllable, termed an ambisyllabic consonant. Ambisyllabicity occurs under certain stress conditions, basically when the following vowel is unstressed. When we consider the syllable affiliation of consonants, there are thus three possibilities in English – syllable final, syllable initial, and ambisyllabic – as exemplified by the following near minimal set: *bean* /bín/, *be neat* /bì\$ní/ and *beanie* /bíni/. (Here and in the subsequent discussion, \$C indicates (absolute) syllable initial position.) Characterization of syllable structure in these terms will be seen to play an important role in the subsequent discussion.

5.2. Phonological rules affecting nasality in English

Several rules of English phonology are described as affecting the behavior of a nasal consonant or a segment adjacent to a nasal consonant. In this section, I give a brief overview of

these rules. In the subsequent discussion, the status of these proposed rules will be discussed based on observations of the presented data set. In particular, the nature of application of these rules will be considered: is the result categorial or gradient and how systematically do the rules apply? It will be argued that some of the following rules are phonological, but apply optionally, and that others are actually not phonological, but rather phonetic.

5.2.1. Anticipatory Vowel Nasalization

English is often assumed to have a general rule of Anticipatory Vowel Nasalization of the form $V \rightarrow \tilde{V} / _ N$. Such a rule is widely assumed in introductory discussions of English phonology (e.g. Fromkin and Rodman 1988, Wolfram and Johnson 1982). Such a rule is also often assumed in more research oriented work, usually discussed in relationship to another phonological rule, Nasal Deletion ($N \rightarrow \emptyset / _ \left[\begin{array}{l} \text{-cont} \\ \text{-voice} \end{array} \right]$). If Anticipatory Nasalization is indeed part of the phonology of English, we would expect to see a significant amount of nasalization for most or all of the duration of the vowel preceding a nasal consonant. This expectation follows from our observation of the nature of nasal vowels in French (assumed either to be underlying or derived by phonological rule) and the nasal vowels of Sundanese, derived by a lexical phonological rule of Nasal Spread. If, on the other hand, nasalization results typically for only a portion of the preceding vowel and is observed to occur in a gradient manner, it should be concluded that the nasalization is the result of phonetic implementation rather than a phonological rule.

5.2.2. Nasal Deletion

It has often been assumed that English has a phonological rule of Nasal Deletion of the form $N \rightarrow \emptyset / _ \left[\begin{array}{l} \text{-cont} \\ \text{-voice} \end{array} \right]$: a nasal consonant is deleted when preceding a voiceless stop. The deletion of the nasal consonant is assumed to follow a rule of Anticipatory Vowel Nasalization, as discussed above. This rule ordering makes the underlying nasal consonant recoverable. This process is observed to occur most often with the coronal nasal consonants. Such a rule is assumed quite widely in the phonological literature on English (e.g. Selkirk 1972, Kahn 1976, Hooper 1977).

Evidence for this rule is taken from Malécot's (1960) observations that in forms such as *sent* [sɛ̃t], the nasalization of the vowel is a much more salient cue to the presence of a nasal consonant than is the consonant itself, and that the nasal consonant is often deleted or drastically reduced, resulting in a surface contrast in vowel nasality in forms such as *sent* [sɛ̃t] and *set* [set]. Yet the status of this rule deserves consideration. Malécot also discusses the patterns of "vestigial" nasals and some of the factors that appear to condition their presence. Furthermore, other phonetic evidence questions the categorial nature of Nasal Deletion. In their extensive study of /d/ and /t/, Zue & Laferriere (1979) observe deletion of the nasal consonant in /nt/ clusters only 18% of the time.

Although rarely mentioned (but see Lovins 1978), the application of such a rule appears to be affected by syllable structure. More generally, the effects of a /t/ on a preceding /n/ (whatever the

nature of the effects) are much stronger when /t/ is in (absolute) syllable-final position, fully in the same syllable with the preceding nasal consonant. Both the variable and optional nature of the rule of Nasal Deletion will be considered below.

Note that if the rule of Anticipatory Vowel Nasalization is shown not to be a general rule of English phonology, but Nasal Deletion is a rule of English phonology, there would then be an apparent paradox. Either it must be the case that Anticipatory Vowel Nasalization occurs in just those cases where Nasal Deletion might occur (requiring some sort of global power); or it could be the case that Anticipatory Vowel Nasalization occurs as a result of Nasal Deletion, rather than being ordered before it. Under this view, when the nasal consonant is deleted, the [+nasal] specification remains and links to the preceding vowel. This would result in effects similar to the "Nasal Stability" effects in French argued for by Piggott (1987). Were this the case, one would expect significant nasalization of these vowels in a quite categorial fashion, in contrast to those where there are more gradient effects resulting from phonetic implementation. If the nasal consonant were deleted without leaving its [+nasal] specification, then there should be no phonetic nasalization of the preceding vowel; e.g. *sent* /sent/ [sɛ̃t] would be expected to be homophonous with *set* /set/ [set]. This is clearly not the case.

5.2.3. Glottalization

Both Selkirk (1972) and Kahn (1976) describe Glottalization of /t/'s in certain environments, although the environments described in the two works are slightly different. Kahn describes Glottalization as follows: [-cons] t \$ → [+constricted glottis]: syllable final /t/ is glottalized following a [-consonantal] segment. Selkirk's (1972) formulation of what she calls Glottal Reinforcement is as follows: Glottal reinforcement occurs in the environment / [+sonorant] ___ [-seg]₀ C, where [-seg]₀ refers to various types of boundaries. These two formulations make different predictions for application in the case of a word-final /t/ before a vowel-initial word which is not resyllabified, and in the case of a /t/ following an /l/ or a nasal consonant. The applicability of Glottalization with respect to the presence of a preceding nasal consonant is clearly of importance here. Kahn presumably states the environment as he does because he assumes that the /n/ will have already been deleted. Yet when the /n/ is not deleted, it is often shortened and glottalized; the presence of such vestigial nasal consonants might be taken as support for Selkirk's characterization of the left environment.

5.2.4. /d/ & /t/-Deletion

Selkirk discusses two closely related rules of Coronal Stop Deletion which occur when a coronal stop is between two consonants:

- (3) a. t, d → Ø / [-son] ___ (#) C
- b. t, d → Ø / $\left[\begin{array}{c} C \\ +nasal \end{array} \right] _ _ (\#) C$ (Selkirk 1972, p. 192)

Both /t/ and /d/ delete when preceded by a [-sonorant] or a [+nasal] consonant and followed by (an optional boundary and) a consonant. The second rule results in a difference in the output

for /t/ and /d/, since Glottalization precedes this rule. The /d/ is argued to delete completely, whereas there is a trace of the /t/, as Glottalization affects the preceding nasal. Selkirk notes the following: "It seems that the Post-Nasal Elision Rule [3b] may delete the articulatory features of a voiceless consonant that are related to the mouth cavity, but not affect the glottal closure associated with that consonant." (Selkirk 1972, p. 195). This insight is quite straightforwardly captured under a view where the glottal features and supra-laryngeal features are on separate tiers or constitute different branches of a featural tree. The laryngeal features could spread to the left onto the nasal consonant before the deletion of the /t/, or they might be left floating by the deletion of the /t/ (a stability effect) and dock on to the preceding segment. Below we will see that Glottalization must precede /t/-Deletion, since the effects of Glottalization are observed on a preceding nasal even if the /t/ is subsequently deleted.

The status and behavior of each of these proposed rules will be taken up below, following a presentation of the relevant cases. Zue and Laferriere (1979) assume that Glottalization is a phonological rule and that Vowel Nasalization and Nasal Deletion are "low-level phonetic rules". They imply that phonological vs. phonetic rules can be determined by regularity of application: non-regularity of application equals phonetics. This is quite a general view, as many interpret "gradient" to mean "variable", but as defined in Chapter 1, these terms are used distinctly here. We consider below whether Zue and Laferriere's conclusions regarding these rules correspond with ours.

5.3. The data

5.3.1. The data collection

The primary goal in this part of the study was the construction of a data set which closely paralleled the data set for French. An extensive minimally contrasting data set was constructed in order to examine both nasal and oral segments in a range of segmental contexts and to allow cross-linguistic comparison. The possible contexts are more limited than in French, since there is no phonological contrast between nasal and non-nasal vowels in English.

The effects of nasalization in English have been discussed widely in the literature. The previous studies include x-ray studies (e.g. Moll 1962, Lubker and Moll 1965 (with simultaneous airflow), Moll and Shriner 1967, Moll and Daniloff 1971, Kent et al. 1974, Kuehn 1976 and more recently Vaissière 1988), electromyographic studies (e.g. Lubker 1968 (with simultaneous x-ray), Bell-Berti 1976 and 1980), fiberoptic or mechanical studies (Ohala 1971, Bell-Berti 1980, Krakow 1989); see Bell-Berti 1980 for a concise review of previous work on velum movement in English.

Yet none of these studies offers a data set extensive enough for full consideration of the issues discussed here. Most of these studies were based on fairly limited corpora, in terms of both segment type and context, and only a few present change over time. Results from previous studies will be included where relevant.

The study of English reported on here is based primarily on recordings of two male speakers of American English from Northern California. When "English" is referred to, what is meant is American English as spoken by these two speakers. No claims are intended more generally about other dialects of English. All forms collected are real words and were recorded with minimally

contrasting control forms. The word list is presented in Appendix C along. The two speakers studied are very similar in most respects. The proposed analysis accounts for both speakers, except for the discussion of glottalization (§5.6), where we focus primarily on Speaker E-C, since he shows much more pervasive effects.

5.3.2. The data: two caveats

Two caveats need to be made about the English data, concerning variability and segmental and prosodic effects on segment duration.

5.3.2.1. Variability in the data

Both speakers of English studied in this investigation show much greater variation within types (across tokens of the same form) than the speakers of either French or Sundanese. As a result, the generalizations drawn from these data are necessarily less systematic and less conclusive than those for the speakers of French and Sundanese, where across tokens the generalizations were very robust.

Some of the observed variability is hypothesized to be due to the fact that there is less phonological specification of the feature Nasal in English (as discussed below in §5.4.4 and §5.7), but some of it, particularly variation in the finer details, is not possible to explain without further study. In order to fully resolve this issue, we would need to study many more speakers of each of the three languages. Only then could it be determined whether it is just coincidental that the two speakers who display the most variability are both speakers of English, or whether such variability is somehow more typical of English. This question must unfortunately remain unanswered in present study.

5.3.2.2. Segmental and prosodic effects on segment duration in English

In our observations of French and Sundanese, fairly stable duration patterns across contexts were observed (with some duration differences between segments in monosyllabic vs. polysyllabic words, as expected). English, on the other hand, shows significant duration differences due to syllable structure, stress and segmental context (cf. Klatt 1976, Lovins 1978, Raphael, Dormann and Freemann 1975, among others). Marked differences in duration can be observed, for example, in the duration of the nasal consonant in a near minimal pair such as *beanie* /bɪni/ and *beat* /bi\$nit/. In these cases, the stress pattern is different and consequently the syllabification differs as well, with the nasal being ambisyllabic in the former case and syllable initial in the latter. In the former case, the nasal consonant is much shorter than in the latter, as shown by the average duration measurements in (4).

(4) Average duration measures (in ms) of ambisyllabic vs. syllable initial nasals for Speaker E-F

	Token#	1	2	3	4	5	Average
ambisyllabic:	/bɪni/	70	40	50	55	50	53
syllable initial:	/bi\$nit/	90	95	95	115	130	105

The ambisyllabic case is half as long as the syllable initial case on the average, 53ms compared with 105ms. (Of course, many more tokens would need to be considered in order to establish the statistical significance of this difference.) The ambisyllabic environment is the same environment where flapping of oral alveolar stops occurs, segments which are notoriously short. But a similar difference is also observed for bilabial nasal consonants, such as *Elmer* [élmə̃], where the /m/ may be ambisyllabic (average 87ms for five tokens) vs. *tell more* [tèl#mór], where the /m/ is syllable initial (average 119ms for five tokens), so it is not the case that such differences in timing are due purely to a phonological rule of Flapping of alveolar stops. (Although since the difference is greater in the alveolar cases, Flapping appears to be partially responsible.) Such shortening affects not only nasal consonants, but is part of the more general timing patterns of English. Such effects would be accounted for by a more comprehensive model of timing independently needed to account for the timing facts of English.

Ultimately, in order to fully understand the patterns of nasalization in English, a model of timing is needed, but such a model is beyond the scope of this study. If it were the case that the effects of nasalization were in terms of absolute timing, then these effects of duration would confound the analysis. But as it turns out, most of the observed effects of nasalization in this study appear to be timed relative to the segment, independent of the duration of particular segments; for example, a nasal consonant is nasalized for its full duration whether its duration is 53ms or 105ms. (This supports Al-Bamerni's (1983) conclusion that the role of contextual effects in nasalization rules out a model of time locking.) Since the observed effects can be characterized in terms of relative timing, the patterns of nasalization can be analyzed independently of duration.

In the subsequent discussion, we focus on the realization of non-nasal segments in the context of nasal segments, since these are the most interesting cases to consider. Overall, we consider three classes of patterns: the effects of the presence of [+nasal] on vowels (both preceding and following a nasal consonant) (§5.4); the effects on longer sequences including [+continuant] consonants and vowels (§5.5); and effects on [-continuant] consonants (§5.6). The approach taken in Chapter 4 will be seen to work in its broad outlines, but will need to be modified to account for the fact that the effects are less extensive than predicted and to account for variability. These issues emerge more clearly in the English data than for either the French or Sundanese, since the phonological representation for English is sparser.

5.4. Nasalization of vowels in English

We consider now the effects of a nasal consonant on either a preceding or a following vowel in English. As will be seen below, there is extensive nasalization of vowels in both of these environments. One of the central questions to be addressed in this section is whether such effects are phonological or phonetic.

5.4.1. Predicted patterns

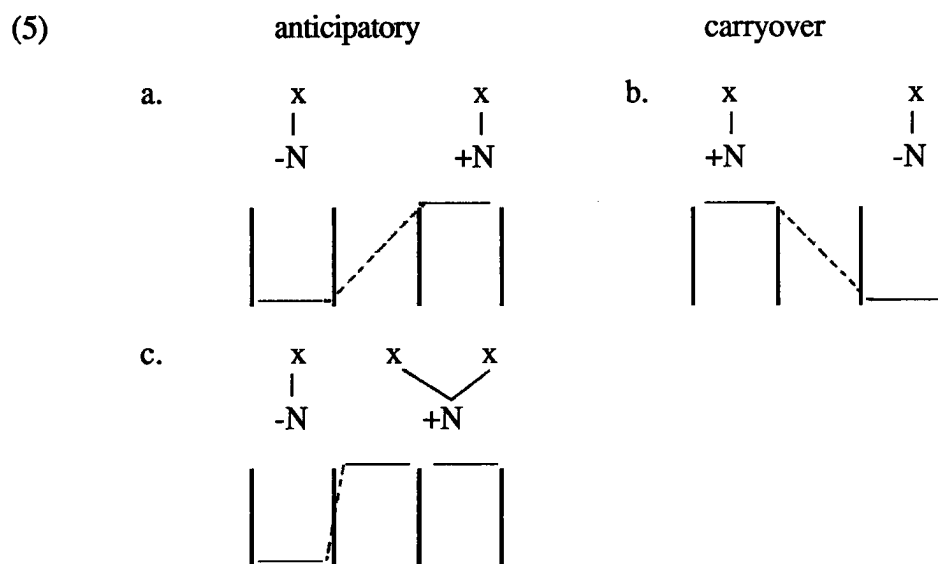
In trying to sort out the status of nasalization on vowels in English, we have a few tools to assist us. First, we have the general heuristic of phonological effects being categorial and phonetic effects typically being gradient. We also have more specific information to draw on from our observations of both French and Sundanese. In the data from French, we observed that nasal

vowels were nasalized for most of their duration, starting at the onset of voicing, or at most 20-30ms later when following a stop, and continuing until the end of the segment. The absolute amounts of flow for [ʃ] and [ʒ] were observed to be different, due to differences in oral impedance, but in both cases there was full nasalization of the segment. In Sundanese, we observed significant nasalization of the full duration of a vowel following a nasal consonant, in the environment of the phonological rule of Nasal Spread. We concluded then that a vowel which is specified as [+nasal] at the output of the phonology will be realized as significantly nasalized throughout most or all of its duration. This is predicted by our model, since any feature specification is mapped to a target which is most of the duration of the segment.

If nasalization of vowels in English is systematic and occurs for most of the duration of the segment, regardless of vowel quality and context, we will conclude that it is the result of the vowel being specified as [+nasal] at the output of the phonology. If, however, the results are more gradient, we will conclude that the effects are phonetic.

A priori, we have no reason to expect that the effects of nasalization in English are anything but phonetic. Yet, as noted above, claims have been made in the phonological literature of the existence of a phonological rule of Anticipatory Vowel Nasalization in English. This runs into problems when we consider carryover effects. In the phonetic literature, there is discussion of both anticipatory and carryover effects of nasalization. It has been claimed that the anticipatory effects are stronger than the carryover effects (e.g. Moll 1962, Ohala 1971), as claimed more generally for coarticulation, but as noted by Al-Bamerni (1983) and as observed in the present study, carryover effects may be as strong or stronger. Yet, to my knowledge, no claims have been made that carryover nasalization has phonological status in English. Thus another potential test of the status of anticipatory nasalization in English is a comparison with mirror-image carryover cases.

Consider the expected patterns schematized in (5):



In (5a & b), the outputs expected from phonetic interpolation are shown for the anticipatory and carryover cases respectively. In each case, we would expect to see a cline throughout the

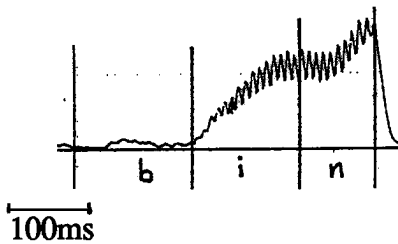
duration of the vowel. If, on the other hand, there is indeed a phonological rule of Anticipatory Nasalization, we would expect to see a pattern for the anticipatory case such as the one in (5c) with both the vowel and the following nasal consonant fully nasalized. Note that in earlier work within the phonetic literature which assumed that vowels were unspecified for velum position in English (Moll and Shriner 1967, Moll and Daniloff 1971), a pattern such as (5c) was nevertheless predicted. Since these works assumed a Henke type "look-ahead" model, the upcoming specified value was switched to as soon as possible, i.e. at the very beginning of an unspecified span.

5.4.2. Nasalization of vowels in English

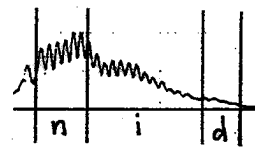
Consider the example flow traces for VN and NV cases in English presented in (6):

(6) VN and NV cases

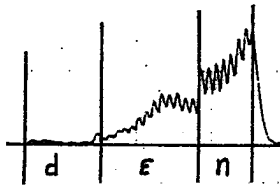
a. *bean* /bin/ [E-C 1]



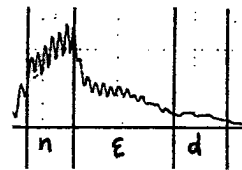
b. *need* /nid/ [E-C 3]



c. *den* /den/ [E-C 1]



d. *Ned* /nɛd/ [E-C 2]



We see that both the anticipatory cases (6a & c) and the carryover cases (6b & d) show changing amplitudes of flow throughout the duration of the vowel. We thus observe the cline-like patterns predicted if these vowels are unspecified for the feature Nasal leaving the phonology and receive quantitative levels of flow through interpolation. These patterns occur across different consonantal places of articulation, different vowel qualities and different stress patterns, although some variation in the shape of the amplitude of flow is observed, as discussed below in §5.4.4. (In the previous literature, little attention is given to the shape of the amplitude of flow, or the change over time of velum movement; yet within the present model, not only the presence or absence, but the specific pattern of nasalization is relevant.)

The anticipatory cases do not show plateau-like amplitudes of flow as would be expected if they were specified as [+nasal] at the output of the phonology. Yet there are two sets of systematic exceptions to this generalization, where plateau-like patterns are observed: (1) vowels preceding tautosyllabic NT clusters (e.g. *sent* /sent/), discussed below in §5.6.3; and (2) vowels preceding a nasal consonant and following a voiceless stop or /h/, discussed below in §5.4.5.

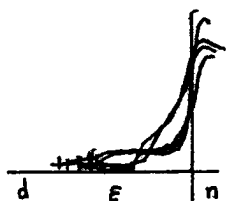
The basic patterns observed are consistent with there not being a general phonological rule of Anticipatory Nasalization in English. In what follows, we pursue a bit further the comparison of anticipatory and carryover cases as additional evidence for this conclusion.

As discussed above, it is often assumed that there is a phonological rule of Anticipatory Vowel Nasalization, but no such claims have been made about carryover nasalization, and it is also widely assumed that phonetically anticipatory effects of nasalization are stronger than carryover ones. In light of these assumptions, it is worth comparing anticipatory patterns of nasalization with carryover ones.

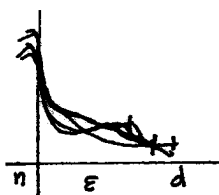
In order to make a systematic comparison, mirror image cases need to be considered. There are several such pairs in the corpus. In (7), three such pairs – *den-Ned* /dɛn - nɛd/, *dean-need* /din - nid/, and *pen-net* /pɛn - nɛt/ – are presented with the five tokens for each type overlaid.

(7) Mirror image cases: VN and NV – five tokens superimposed Speaker E-F
(four tokens of /pen/)

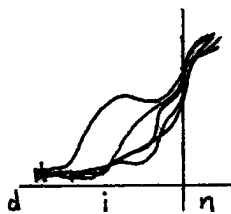
a.i. *den* /dɛn/



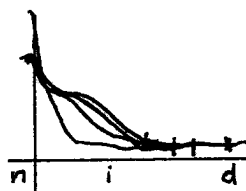
ii. *Ned* /nɛd/



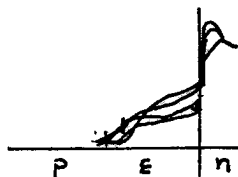
b.i. *dean* /din/



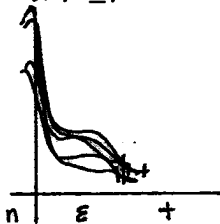
ii. *need* /nid/



c.i. *pen* /pɛn/



ii. *net* /nɛt/



In (7a), there is noticeably more carryover than anticipatory nasalization. In the remaining two cases (7b & c), the extent of flow looks comparable. We have no expectation that carryover nasalization in English is the result of a phonological rule and yet we observe as much or more carryover nasalization as anticipatory. This too supports the conclusion that there is no general phonological rule of Anticipatory Vowel Nasalization in English.

Even though there is more carryover nasalization than anticipatory nasalization in raw flow terms in English, this does not mean we should conclude that there is a phonological rule of carryover nasalization in English. There is still less flow and it is more variable than we would expect it to be if it were a result of a phonological rule, such as the Nasal Spread rule of Sundanese. There is no reason to assume that the status of carryover nasalization is any different from anticipatory nasalization in English. Both cases appear to be the phonetic effect of a neighboring [+nasal] segment through an unspecified span. Both the anticipatory and carryover cases in English are consistent with an analysis of phonetic interpolation.

Carryover nasalization is as strong as or stronger than anticipatory nasalization in English, yet it is anticipatory, not carryover nasalization, that is often claimed to be phonological. This raises the question of perception of nasalization. It would be beyond the scope of this study to pursue this question, but it may well be the case that anticipatory nasalization is perceptually more salient than carryover nasalization. (Some studies have addressed general issues of perception of nasalization, e.g. Ali, Gallagher, Goldstein and Daniloff 1971, Beddor and Strange 1982, Lahiri and Marslen-Wilson 1988; but no study, to my knowledge, has focussed on the perception of carryover cases.)

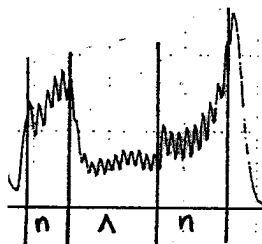
5.4.3. Phonetic interpolation: vowel nasalization in English

The observed patterns of vowel nasalization in English can be accounted for in a straightforward manner within the framework constructed in Chapter 4. We assume that [-continuant] consonants are all specified, as either [+nasal] or [-nasal]. The vowels in English generally remain unspecified at the output of the phonology, receiving some nasalization through phonetic interpolation.

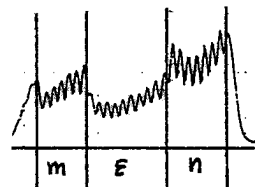
There is evidence that, phonetically, vowels in English are not fully unspecified, but rather have minimal phonetic constraints, consisting of a wide window – a wide range of possible values. As noted in Chapter 4, based on x-ray evidence (Kent et al. 1974), there is a limit on possible velum lowering during vowels (in our terms a ceiling on the amount of nasal airflow). This is taken by Keating (1988) as support for her window theory and integrated here into a more general framework of phonetic constraints. The NVN tokens collected in the present study are consistent with this view, as exemplified in (8).

(8) NVN patterns

a. *none* /nʌn/ [E-C 1]



b. *men* /mɛn/ [E-C 5]



adjacent, no priority statements are in effect. Finally, there is interpolation between targets, within the phonetic constraints. This results in rising and falling clines during the vowels in (9a & b) respectively, and a plateau with rapid transitions at the edges during the vowel in (9c). The patterns of phonetic interpolation observed here are very similar to those patterns observed in French in which an "oral" vowel was unspecified. We assume that the phonetic constraints are similar, although it may well be the case that the windows for vowels in English are wider than in French.

5.4.4. Accounting for variability

The proposed analysis assumes that there is smooth interpolation through the unspecified vowels (as restricted by the phonetic constraints). Yet if we look more closely at the data, we observe significant variability in both timing and shape of flow. Recall that what is meant by variability is a difference in the realization of different tokens of the same form. Take for example five tokens each of the forms *dean* /din/ and *neat* /nit/ shown in (10).

In each of the five tokens in (10a), we observe cline-like nasalization during the vowel, consistent with the view that this is a result of phonetic realization. Yet the point of onset of nasalization and the finer details of the shape of the amplitude of flow during the cline vary noticeably. Even though the duration of the vowel (V) is fairly constant (150-200ms), the duration of the nasalized portion (~) varies significantly (50-150ms), as does the proportion of the vowel that is nasalized (calculated as a ratio of $\frac{\text{nasalized duration}}{\text{vowel duration}}$, %N; .33 - .79).

As with the anticipatory cases, considerable variability occurs in the carryover cases, as shown in (10b). Again vowel duration is fairly constant (105-155ms), but finer aspects of shape, duration of nasalization (40-130ms) and %N (.31-1.19) all vary noticeably. (One case (10bii) actually shows more of a plateau than a cline.)

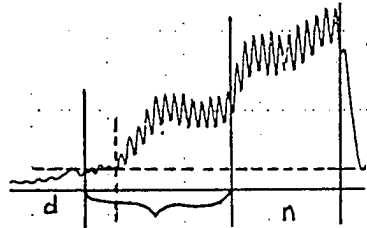
First we note that no such variability was observed on vowels argued to be [+nasal] leaving the phonology in either French or Sundanese. Rather, as noted above, such segments were fully nasalized in a significant way for all or most of their duration. Such variability is inconsistent with the view that these segments are phonologically specified, since such specifications would be expected to be more systematically realized in the phonetics. This observed variability can then be taken as an additional argument against a phonological rule of Anticipatory Nasalization in English.

Yet we still must account for this variability in the phonetic implementation. One of the arguments that Keating makes in support of her window model is the existence of variability, in her terms, different paths through a window. (She predicts the greatest variability when a segment is in isolation, as no constraints from context are expected in such cases. In the present study, there were no segments in isolation so we cannot compare to see if even greater variability is observed in such cases.)

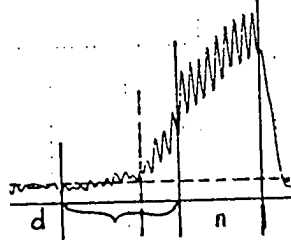
(10) Five tokens of *dean* /din/ and *neat* /nit/, Speaker E-F
 ~ = duration of nasalized portion, V = duration of the vowel
 %N = proportion of the vowel that is nasalized

a. *dean* /din/

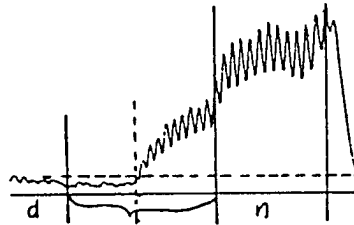
i. ~ = 150 V = 190 %N = .79



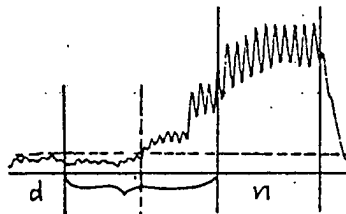
ii. ~ = 50 V = 150 %N = .33



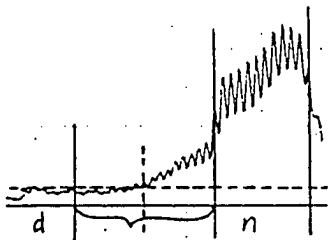
iii. ~ = 105 V = 190 %N = .55



iv. ~ = 100 V = 200 %N = .5

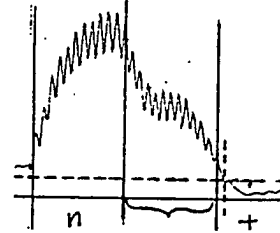


v. ~ = 90 V = 180 %N = .5

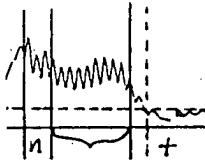


b. *neat* /nit/

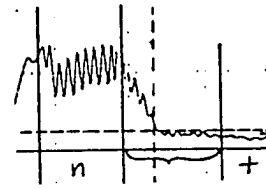
i. ~ = 130 V = 120 %N = 1.08



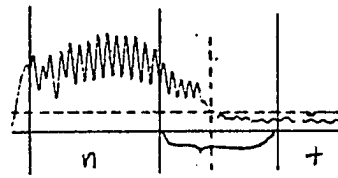
ii. ~ = 125 V = 105 %N = 1.19



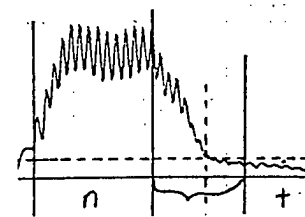
iii. ~ = 40 V = 130 %N = .31



iv. ~ = 70 V = 155 %N = .45



v. ~ = 70 V = 120 %N = .58



Often it appears to be the case that a fairly wide range of shapes, or interpolation functions, are allowable. Thus through any particular window, a range of acceptable paths are possible as schematized in (11).

(11) Possible paths through a window



I assume that the patterns such as those in (10) result from these different paths. We see that these paths are all possible ones in this case, yet ideally we would like to better understand why we do or do not observe variability in particular cases. It is interesting to note that there is nevertheless a tendency to straight interpolation, the most direct path.

5.4.5. Some exceptions

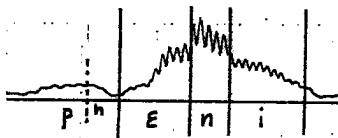
As noted above, there are two classes of exceptions where plateau-like nasalization is observed on a vowel preceding a nasal consonant.

5.4.5.1. The cases

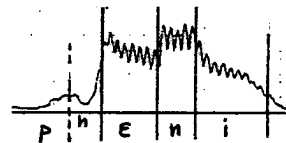
In many of these cases, there is more than full nasalization; that is, the onset of nasalization precedes the onset of the vowel. In (12) three tokens of *penny* /pɛni/ are presented, comparing examples of full nasalization, more than full nasalization and cline-line nasalization.

(12) Three tokens of *penny* /pɛni/, Speaker E-C

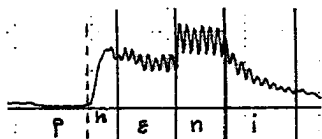
a. cline-like [E-C 3]



b. full nasalization [E-C 4]



c. more than full nasalization [E-C 1]



In (12a), there is a typical cline-like pattern of nasalization on the /ɛ/ preceding the /n/; in (12b) the onset of nasalization coincides with the onset of the vowel; and in (12c) the onset of nasalization is before the onset of the vowel.

In (13) a list of tokens of VN forms that could be characterized as fully or more than fully nasalized for both speakers is presented. (Besides those listed in (13), there are a few additional cases of full nasalization for Speaker E-C, that seem to be sporadic; for example in *den* /dɛn/ [E-C 4], there is a brief period of nasalization before the release of the voiced stop. Without further investigation, no firm conclusions can be drawn about such cases.) We leave aside, for the moment, cases where the vowel is a diphthong or followed by a liquid in the rime (in other words, cases where a glide or liquid occurs between the vowel and following nasal consonant). The cases are listed by speaker with separate columns for full nasalization (Full ~) and more than full nasalization (> Full ~).

(13)	Speaker E-F		Speaker E-C	
	Full ~	> Full ~	Full ~	> Full ~
appender	/əpɛndə/	[3]	[4]	[2, 3, 4, 5]
Henry	/hɛri/		[3, 4, 5]	[1, 2, 3, 4]
kennel	/kɛnəl?	[1]		[2, 4]
pen	/pɛn?		[2]	[2, 3] [4]
penned	/pɛnd?		[1, 4]	[3] [4]
pen letter	/pɛnlɛtə/			[1, 2]
penny	/pɛni?		[3]	[4] [1]
pent	/pɛnt?	[5]	[1, 2, 3]	[3] [2, 4]
repenter	/rɛpɛntə/		[2]	[2] [3, 4, 5]
sent	/sɛnt?	[2]		[3] [1, 2, 4, 5]
tenor	/tɛnə/			[1, 2]

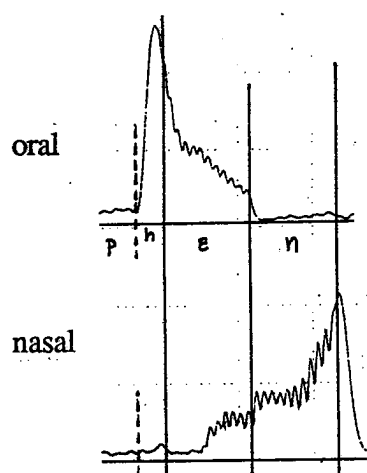
Several generalizations emerge about where full (or more than full) nasalization can occur. (1) Full nasalization occurs more frequently for Speaker E-C than Speaker E-F, but it does occur for both speakers. (2) For both speakers, it occurs in the same forms, or at least the same patterns of forms, but in each case, it is not systematic; in a particular form, full nasalization does not occur in all of the ten tokens. (3) In all of the cases where full nasalization occurs, the affected vowel is /ɛ/. This is an artifact of the data set, as this was the vowel most systematically studied. There are other forms with /ɛ/ where full nasalization is not observed (e.g. *den* /dɛn/) and there are forms with other vowels where similar patterns occur (not listed here, because they involve diphthongs, e.g. *kindness* /kajndnɛs/). (4) Full nasalization may occur if there is a tautosyllabic /t/ following the nasal consonant, *sent* /sɛnt/ and *pent* /pɛnt/, discussed below in §5.6.4. (5) Finally, full nasalization may occur if the consonant preceding the vowel is an aspirated voiceless stop or /h/. In the stop cases, the onset of nasalization either coincides with the onset of aspiration or occurs after the onset of aspiration. It is this latter generalization to which we now turn.

5.4.5.2. The effects of aspiration on nasalization

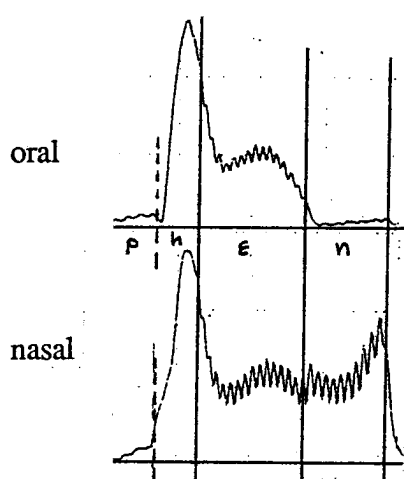
Let us look in more detail at some examples of nasalization of an aspirated voiceless stop or /h/ preceding a nasal consonant (with an intervening vowel). In the following examples presented in (14), both nasal and oral airflow are presented, since oral airflow is very high during aspiration and /h/ and therefore might magnify the effect of slight nasalization.

(14) Speaker E-C nasal and oral flow

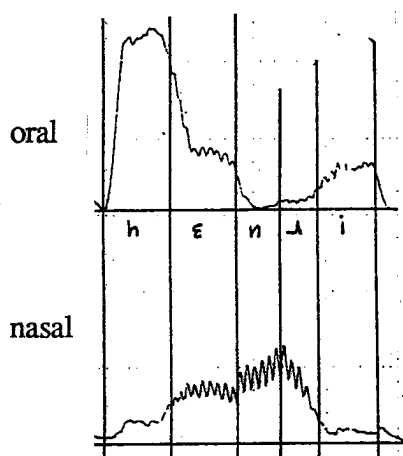
a.i. *pen* /pɛn/ [E-C 5]



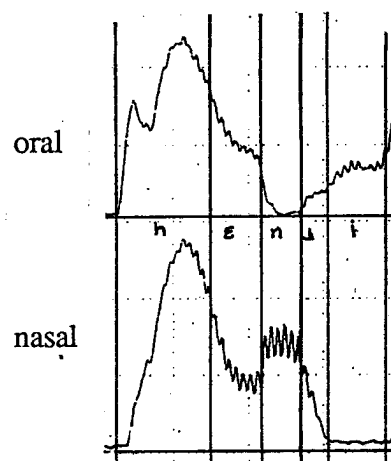
a. ii. *pen* /pɛn/ [E-C 4]



b.i. *Henry* /hɛnri/ [E-C 5]



b.ii. *Henry* /hɛnri/ [E-C 3]



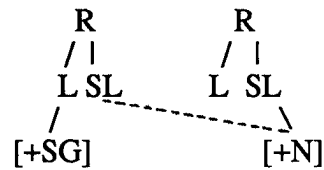
In (14), examples with full nasalization are compared with the otherwise expected cline-like pattern for such forms. In (14ai), a cline-like pattern of flow during the vowel is observed, as expected. In (14a ii) an example of more than full nasalization is shown for the same form. Here we observe that the onset of nasalization coincides with the onset of aspiration, as seen by comparing the oral and nasal flow traces. The marked spike in nasal airflow parallels the observed changes in oral airflow; these changes are due to overall changes in rate of flow through the glottis. When the effects of change in overall rate of flow are factored out, there is probably more or less a plateau of nasalization, starting at the stop release. The fact that the observed nasalization is not an artifact of the overall high rate of flow can be seen through a comparison with (14ai), where a similar pattern of oral flow is observed, even though there is no sign of nasal flow at the onset of the vowel. In (14b), two examples with /h/ are seen, (14bi) with no nasalization of the /h/ and cline-like nasalization of the vowel and (14bii) with strong nasalization of the /h/ starting at the onset of the /h/. Here again, the marked spike in nasal flow parallels the observed pattern of oral flow. The aspirated stop and /h/ cases are similar, except that in the nasalized /h/ cases, the full

segment is nasalized, whereas in the nasalized aspirated voiceless stop cases, only the period of aspiration, not the closure is nasalized. The similarity between the behavior of /h/ and the aspiration portion of a voiceless aspirated stop is not surprising. Phonetically they are basically the same: a period of opening of the glottis (wide enough to inhibit vocal cord vibration). In terms of most current feature systems, both aspirated stops and /h/ are [+spread glottis] (+SG) (following Halle and Stevens 1971).

What appears to be happening in these cases is that aspiration can be nasalized. This observation fits in with both phonetic and historical observations regarding the close connection between nasalization and /h/ (see Ohala 1975, Matisoff 1975). Yet, in the present study, such nasalization is not spontaneous, but is triggered by the presence of the following nasal consonant; since the aspiration is never nasalized in cases such as *pet* /pet/ and *ped* /pɛd/.

To account for this observation, I propose a phonological rule of [+Spread Glottis] Nasalization.

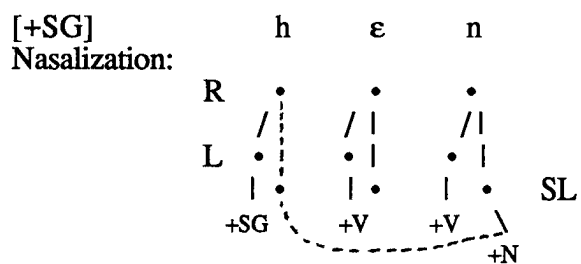
(15) [+Spread Glottis] Nasalization applies optionally



A [+nasal] specification may spread back to a segment specified as [+spread glottis]. This rule does not delink an existing Nasal Specification, resulting in a contour segment in the case of a voiceless aspirated stop. This rule must be optional, since it applies in cases like (14aii and 14bii), but not (14ai and 14bi). (Note that the use of the term "optional" is misleading, since in all likelihood the application or non-application of an "optional" rule is conditioned by a range of factors, both linguistic and paralinguistic.)

Let us consider how this rule would apply in the /h/ case first, then return to the aspirated stops. In a word such as *Henry* /hɛnri/, I assume that the /h/ is underlyingly specified as [+spread glottis], but unspecified for any supralaryngeal features, including Nasal. The vowel is phonologically unspecified for both Spread Glottis and Nasal. The phonological representation for the relevant part of the form is shown in (16) with solid lines.

(16) Phonological derivation of *Hen(ry)* /hɛn(ri)/

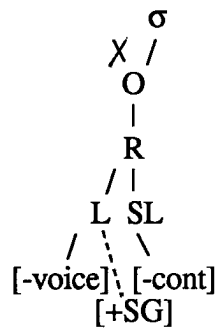


Phonological Output: hɛ̃nri

The representation in (16) meets the structural description of the rule of [+Spread Glottis] Nasalization. Since the vowel is unspecified for Spread Glottis, the /h/'s [+spread glottis] specification is adjacent; and since the vowel is unspecified for Nasal, it does not block the spreading of the [+nasal] specification. The application of this rule is indicated by the dashed line. Note that I assume that the application of this rule automatically generates a Supralaryngeal node. The /h/ is, therefore, nasalized. The vowel is also nasalized. This could be accounted for either phonologically, by assuming intervening unspecified Nasal values also get filled in due to the application of the rule, or phonetically, due to interpolation between two nasal targets. Since there is no obvious way to choose between these two approaches, for the sake of concreteness, I assume the latter.

The case involving nasalization of aspiration of voiceless stops is more complex, since such segments are not underlyingly aspirated. Rather aspiration is an allophonic rule of English (see Kahn 1986 among others) and is typically assumed to be a late phonological rule. Before studying the effects of the proposed rule of [+Spread Glottis] Nasalization, we need to consider the form of the Aspiration Rule. I assume that Aspiration in English is as follows:

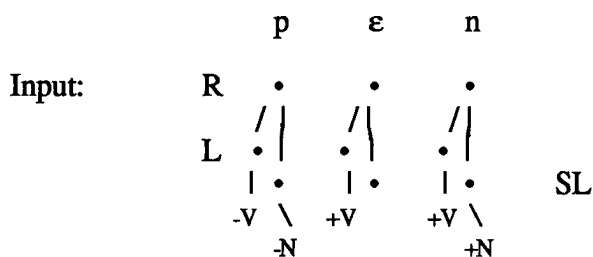
(17) Aspiration Rule



A voiceless stop in absolute syllable initial position becomes aspirated ([+spread glottis]). (The location of Continuant in the feature hierarchy, a topic of some debate (see McCarthy 1988), is not relevant to the current discussion.)

The proposed rule of [+Spread Glottis] Nasalization must necessarily be ordered after Aspiration, since the latter feeds the former, as illustrated in the following phonological derivation of *pen* /pɛn/:

(18) Phonological derivation of *pen* /pɛn/

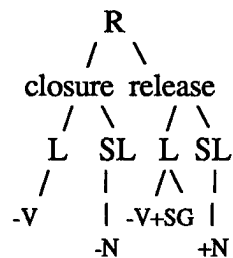


Abramson 1964, Keating 1984). Under this type of view, the static phonological representation must be realized in time in the phonetics. (An alternative view is that timing is more directly represented in the phonology. Few models incorporate timing in this way, but cf. Browman and Goldstein's (1986) view of phase relations.)

Steriade (1989) has proposed that in their surface representations, stops consist of both a closure and release portion. In her view, this is part of the surface phonological representation, but not the underlying representation, of a stop. Somewhat parallel to this view are Kingston's (to appear) theory of articulatory binding, where laryngeal events are seen to bind with stop releases and Huffman's (1989) theory of landmarks, where in the phonetics both the beginning (the closure) and the release of stops play a role in phonetic implementation. For the issues under consideration here, we need not resolve the question of whether this two phase view of a stop exists in the surface phonology or only in the phonetics; in what follows, I present surface phonological representations, which I believe to be in agreement with Steriade's proposal.

What is important for our analysis is that by the point when targets are assigned for the feature Nasal, the period of aspiration has a status, since the change from [-nasal] to [+nasal] is not in terms of absolute duration, but directly linked to the onset of aspiration. I assume that a [+spread glottis] specification in a stop is relevant only to the release phase of that stop. (Note the phonetic difference between a voiceless unaspirated and voiceless aspirated stop relates to the nature of the release, not the closure.) The representation within which phonetic implementation of Nasal occurs must be as follows:

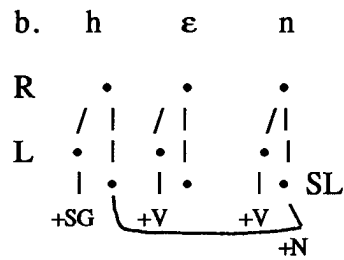
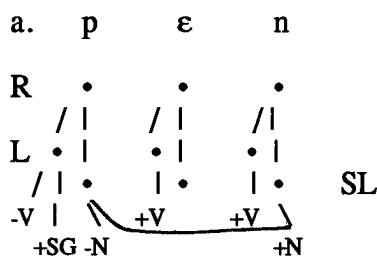
(19) Restructuring of a stop into its Closure and Release phases



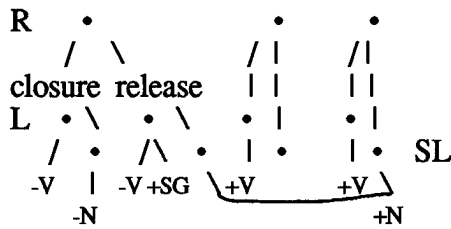
The [+spread glottis] specification is related to the release phase as is the [+nasal] value of the contour nasal specification. Each of these specifications maps to a target. (An independently required model of timing would account for the relative durations of these segment parts.) The phonetic derivations of *pen* /pɛn/ and *Hen(ry)* /hɛn(ri)/ are presented in (20), starting with the phonological output as shown in (18) and (16) respectively.

(20) Phonetic derivations of *pen* /pɛn/ and *Hen(ry)* /hɛn(ri)/

Input:
(from above)



Restructuring into Closure and Release:



Phonetic Implementation:

Target Assignment:



Phonetic Constraints:



Priority Statements:

[-cont] > [+cont] NA

Interpolation:



The outputs of the rule of [+Spread Glottis] Nasalization are repeated from above. At the end of the phonology, Restructuring of the stop into Closure and Release phases takes place. During phonetic implementation, when targets are assigned, in (20a), the [-nasal] specification is assigned a target for the duration of the closure portion and the [+nasal] specification is assigned a target for the release portion. Other targets are assigned as expected. The phonetic constraints are as shown. Based on the rather limited evidence of the behavior of aspiration, no phonetic constraints have been observed. In (20a), the priority statements [-cont] > [+cont] determines that the closure portion should have priority in the transition between the closure and release. Finally, as a result of phonetic interpolation, the intervening vowels also surface as nasalized, constrained only by the ceiling of the phonetic window.

This analysis is consistent with the data in the corpus, albeit limited particularly in forms with /h/. But the analysis also makes clear predictions about other patterns. The proposed analysis predicts that no such nasalization should occur if a voiceless stop is not aspirated, e.g. in a form such as *spin* /spɪn/. Furthermore, it predicts that phonetic nasalization (in a cline-like manner) should be possible in a vowel preceding an hVN sequence, e.g. *a hen* /ə#hɛn/.

The mapping of feature specifications to an aspirated stop in this case raises much more general issues of the nature of target assignment in cases of contour segments. The case presented here suggests that something like landmarks may well play an important role in phonetic interpretation of feature specifications not just between segments, but within segments in cases of contour segments.

The observed facts cannot be accounted for with a purely phonetic analysis, where the observed nasalization of the period of aspiration is due to interpolation between a [-nasal] specification and a [+nasal] specification, with the period of aspiration counting, in effect, as part of the vowel, and therefore unspecified for the feature Nasal. If this were the case, we would expect a cline-like pattern of nasalization throughout both the period of aspiration and vowel.

5.4.6. Conclusion

To conclude this section, we have observed that it is generally the case that nasalization of a vowel adjacent to a nasal consonant results in cline-like effects for both speakers of English under investigation in this study. With the exception of the cases discussed in §5.4.6, all of the relevant data are consistent with the view that such effects are a result of phonetic implementation. We have seen a range of evidence – basic patterns of flow, a comparison of anticipatory and carryover nasalization, and observed variability – consistent with this conclusion. We therefore reject the claim that there is a general phonological rule of Anticipatory Nasalization in English.

The fact that there is phonologically often assumed to be a rule of Anticipatory Nasalization in English may well result from two sources: (1) overgeneralization of a more specific rule which occurs only in the case of a following NT cluster, discussed below in §5.6.4; or (2) a tendency for listeners to impose a categorical interpretation on a gradient effect.

Yet there are also cases in the phonetic literature which are argued to support the view that there is a phonological rule of Anticipatory Vowel Nasalization in English: cases where nasalization is observed for the full duration of a vowel preceding a nasal consonant. These studies examine timing of nasalization rather than timing and amplitude. For example, Zue & Sia (1982) conclude, based on data from a nasal accelerometer, that onset of nasalization in English appears to coincide with the onset of the vowel. In much of our data as well, onset of nasalization coincides with onset of the vowel, but only at a very low level in a cline-like manner. The study of timing alone may be misleading.

Lahiri and Marslen-Wilson (1988), in an interesting study comparing perception of nasalization in English and Bengali, assume that there is full nasalization in the anticipatory environments in English. Their perceptual data show that hearers are sensitive to nasalization very early in a vowel in such an environment, but they present no acoustic, articulatory or aerodynamic data to show what the nature of nasalization is on those particular forms. The nasalization at or

near the beginning of a vowel preceding a nasal consonant may not be a categorial, phonological effect; there may well be a gradient quality to the onset of nasalization, resulting from phonetic implementation, as observed in the present study. It is likely to be a perceptual fact that hearers are sensitive to much lower levels of nasalization before a nasal consonant (or vowel) than after, since there is nothing yet in the context to which the presence of nasalization can be attributed. As noted before, perceptual studies to pursue some of these cases would be very interesting. One particularly interesting case to study would be the perception of different tokens of something such as *pen* /pen/, where in some cases there is full nasalization and others only cline-like nasalization (cf. (14aii) and (14ai) above, respectively).

5.5. Nasalization of sequences of [+continuant] consonants and vowels

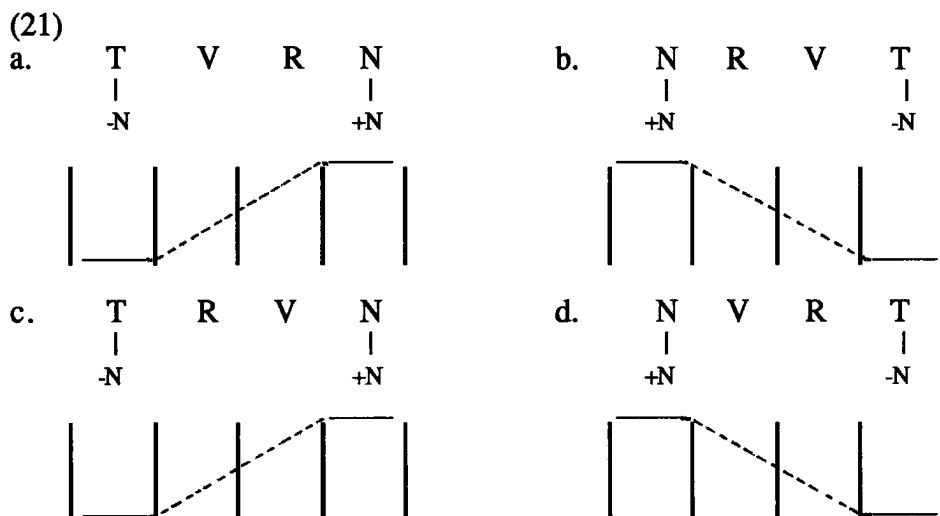
We turn now to the patterns of nasalization in glides and liquids and sequences of glides or liquids and vowels.

I assume that glides are [+continuant]. As observed by Kahn (1976), the phoneme /ɹ/ in English patterns phonologically like a glide and is therefore also assumed to be [+continuant]. It is less clear whether /l/ is [+continuant], [-continuant] or unspecified for the feature Continuant, in English. It seems quite likely, due to the observed allophony of /l/, that it is [-continuant] syllable initially (when it is "light"), since it typically has alveolar contact; and it is either [+continuant] or unspecified, in cases where it loses its alveolar contact, which is often the case when it is velarized ("dark") syllable finally. In any case, independent of its specification for the feature Nasal, it contrasts with nasal consonants due to its [+lateral] specification. No data were collected for fricatives, so we cannot determine whether it is the class of continuant consonants or approximants that behave in the ways described below. In the following discussion, I use the term [+continuant] rather loosely to refer to glides and liquids.

5.5.1. Predicted patterns

Since there is no reason to assume that [+continuant] consonants are phonologically specified for the feature Nasal in English, these cases allow us to consider possible longer range effects of nasalization due to context. A sequence of [+continuant] consonants and vowels, observed to have only very weak phonetic constraints, would be expected to result in cline-like patterns away from the [+nasal] segment over a span of more than one segment. In Sundanese, no such long distance spans are observed, due to the phonotactics of consonant sequences and due to the fact that all vowels are specified for the feature Nasal. In French, such effects over a longer span are marginal and are predicted to arise only in very limited contexts, since in most cases, such potential effects are blocked by the default specification for the feature Nasal of unspecified syllable initial consonants. English, where there are fewer phonological specifications, is predicted to display more long distance effects.

If the [+continuant] segments are indeed unspecified for the feature Nasal and vowels have wide windows, we would expect to see long distance effects such as those schematized in (21). In these schematized phonetic outputs, I am assuming a preceding or following [-nasal] specification and I have left out the details of the local transitions.



The patterns would be expected to be quite similar in these four cases, whether there is an RV or a VR sequence, with cline-like effects in each case throughout the duration of both segments. Patterns (21b) and (21d) would be expected to be the mirror image of (21a) and (21c) respectively.

As we will see, the most general result that emerges is that there is less nasalization than expected. The glides, liquids and vowels are significantly nasalized (usually in a cline-like fashion), when immediately adjacent to a nasal consonant, but not when one of the same class of segments intervenes.

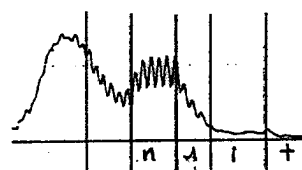
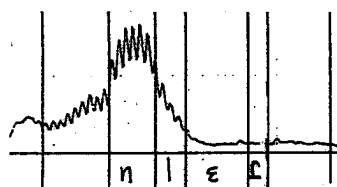
5.5.2. Nasalization over longer distance

The observed patterns are quite consistent across the two speakers. We start first with the NRV carryover patterns, presented in (22):

(22) Representative examples of NRV(S) patterns

a. penletter /penlɛtə-/ [E-C 2]

b. Henry /hɛnri/ [E-D 2]



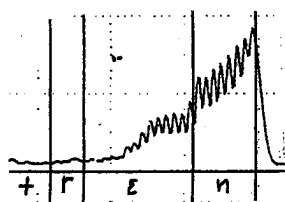
In (22a) we see an example of nasalization of a following /l/ and in (22b) a following /r/ (no cases with an immediately following glide occurred in the corpus). In these examples, we would expect cline-like nasalization throughout the liquid-vowel sequence, yet we observe that there is little or no nasal flow by the onset of the following vowel. Most of the transition from nasal to oral occurs during the segment immediately following the nasal consonant and not over the span of the RV sequence as predicted by our analysis. Although there are only two such forms in the corpus, between the two speakers, of the 20 tokens, 16 clearly have less nasalization than predicted, four

show some nasalization at the beginning of the vowel. What we observe, then, is systematically less nasalization than predicted.

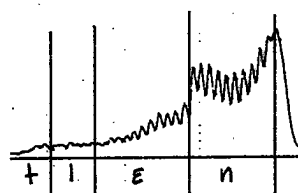
Consider now the RVN anticipatory case, the other case where glides or liquids occur in syllable onset position. Representative examples are given in (23):

(23) Representative examples of (t)RVN patterns

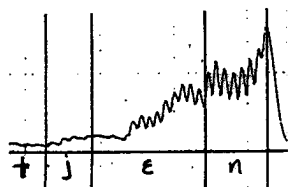
a. *wren* /rɛn/ [E-C 2]



b. *Len* /lɛn/ [E-C 2]



c. *yen* /jɛn/ [E-C 5]



In these cases, we predict a cline starting at the onset of the glide or liquid, continuing through the vowel. Yet as we see in (23), there is cline-like nasalization of the vowel preceding the nasal consonant, but no nasalization of the preceding glide or liquid. Again there is less nasalization than predicted. (Of the forty tokens of this pattern, there are a few cases where there is slight nasalization starting at some point in the liquid or glide; these seem to be sporadic.) These observations are different from those made by Moll and Daniloff (1971), where in the case of lVN or wVN, some velum lowering was observed during the liquid or glide; but their measurements are presented in terms of velum movement, not velum opening, so it is not known at what point opening actually occurs.

So far these observations seem quite similar to the facts observed in French. Recall that in French, a glide or /l/ in syllable initial position was [-nasal] by a default fill-in rule, unless immediately following a [+nasal] specification. Is it the case that a similar Syllable Onset Default Rule is in effect in English as well? Although the patterns look similar, the differences of specification for (oral) vowels in the two languages makes such a solution inadequate in English. In French, in the NRV case, the transition from nasal to oral was restricted to the glide or liquid by the fact that the following vowel was specified as [-nasal] at the output of the phonology. But in English, no such explanation is available for the observed lack of nasalization of the following vowel, since the vowel is assumed to be unspecified at the output of the phonology. Thus these cases in English are not as similar to the French as they might appear. (We will also see additional evidence against such a solution in English in §5.5.4.)

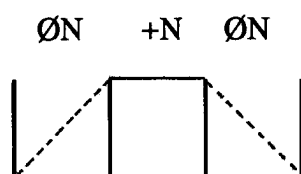
5.5.3. The One Segment Principle

How then can we account for the fact that there is less pervasive nasalization than predicted in these cases? Although there is some variability, it appears that contextual nasalization for these speakers of English affects approximately one segment either preceding or following a [+nasal] specification.

I propose the following principle of phonetic interpolation for the feature Nasal in English:

(24) The One Segment Principle:

In the absence of phonological specification and given no contradictory information, the velum takes approximately the duration of a segment to realize a transition from open to closed or closed to open.



This principle results in a velum-specific interpolatory function. This may relate to a tendency to move toward a speech readiness position, or a default speech position, which is a closed position for the velum. It is well known that the velum typically remains lowered during regular breathing, but raises at the onset of speech. Thus independent from feature specifications, there is a default position for the velum (cf. for example SPE's discussion of neutral speech position). I assume that the One Segment Principle encodes this tendency toward such a default position, tempered by the fact that the velum is sluggish.

Note that there have been some descriptions in the phonetic literature of longer distance effects in English than those observed in the present study (e.g. Moll and Daniloff 1971, Kent et al. 1974, Bell-Berti 1980). These observations, based on x-ray and EMG studies, indicate that there may well be earlier (or later) velum movement, but this may or may not involve actual opening of the velum.

This movement pattern seems to be characterized in terms of duration relative to the segment and not in terms of absolute duration. The fact that it is not absolute duration that is relevant is concluded from the marked range of absolute durations of nasalization observed for both speakers.

As seen above, even with the proposed principle, there is still some variability in the location of the actual turning points of onset and offset of nasalization. Some of this may be due to more subtle effects of phonetic context, which cannot be resolved with the present corpus.

To see how the One Segment Principle works, sample derivations for RVN and NRV cases are presented in (25):

(25) Sample derivations

a. t# l ε n

b. p ε n l ε t ø

Phonological Output:

t l ε n
| |
-N +N

n l ε t
| |
+N -N

Phonetic Implementation:

Target Assignment:

t l ε n

n l ε t



Phonetic Constraints:



Priority Statements:

NA

NA

Interpolation:



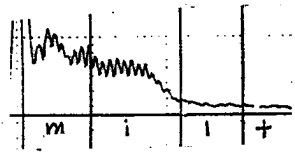
We start with the phonological outputs as shown. Targets are assigned and phonetic constraints are imposed. In addition to the class specific phonetic constraints seen above, the One Segment Principle is imposed, represented here along with the phonetic constraints. The effects of this principle are taken into account in the process of interpolation, limiting phonetic nasalization to one neighboring segment.

5.5.4. More long distance cases

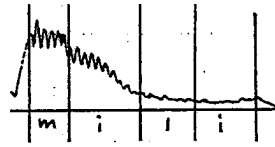
The proposed principle accounts for the two patterns of expected long distance effects discussed for far. We return now to the other two patterns where long distance effects were predicted (as discussed above in §5.5.1.) We consider first the NVR cases, where we will see that the proposed principle accounts for the observed patterns with one slight modification. Example flow traces are presented in (26).

(26) Examples of NVI patterns

a. *meal* /mɪl/ [E-C 1]



b. *mealy* /mɪli/ [E-C 3]



c. *me Lee* /mi\$li/ [E-C 1]



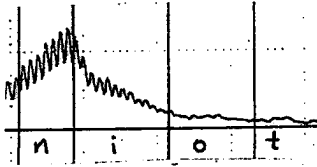
In (26) we see three cases which segmentally consist of a /mil/ sequence, but differ in their syllabic structure. In (26a) the /l/ is syllable final; in (26b) the /l/ is expected to be ambisyllabic; and in (26c) the /l/ is expected to be syllable initial. In all three cases, there is cline-like nasalization of the vowel, but not of the following /l/. These patterns are not significantly affected by syllable structure and are as predicted by the One Segment Principle.

This set of cases provides additional evidence against a Syllable Onset Rule in English, such as proposed for French. In French, a difference was observed between cases analogous to (26a) and (26c), where in the former case nasalization of both the vowel and following /l/ is found; whereas in the latter case, only nasalization of the vowel occurs (with further nasalization blocked by the [-nasal] specification of the syllable initial /l/). No such difference is observed for these speakers of English.

In (27) more examples of the NVR pattern are presented, where some subtle differences emerge.

(27) Representative examples of NVR patterns

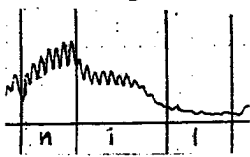
a.i. *neo* /nio/ [E-C 2]



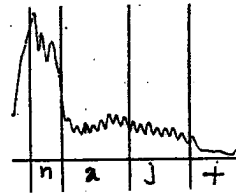
b.i. *naive* /naiv/ [E-C 2]



ii. *kneel* /ni:/ [E-C 5]



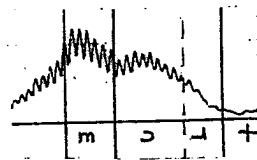
ii. *night* /naɪt/ [E-C 4]



iii. *near* /nɪr/ [E-C 2]



iii. *more* /mɔr/ [E-C 4]

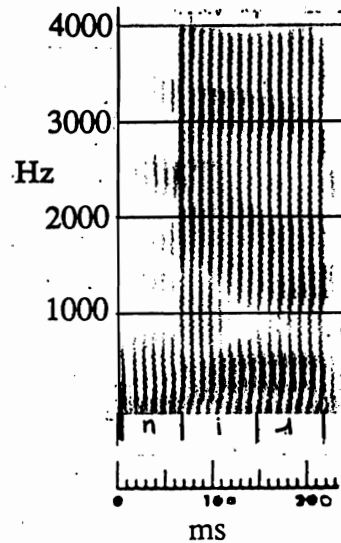


In (27a), we see that the vowel immediately following a nasal consonant is nasalized in a cline-like manner, but the following vowel (27ai) or liquid (27aii & iii) is not. These cases are as predicted by the One Segment Principle, where long distance effects are limited to a single adjacent segment. Yet the observed effects in the examples in (27b) are slightly different. Here two segments may be affected. In the case of (27bi & ii), it is a glide following the vowel (in both cases a diphthong) and in (27biii) it is an /r/ following the vowel. In these cases cline-like nasalization is observed throughout both segments, in apparent violation of the One Segment Principle.

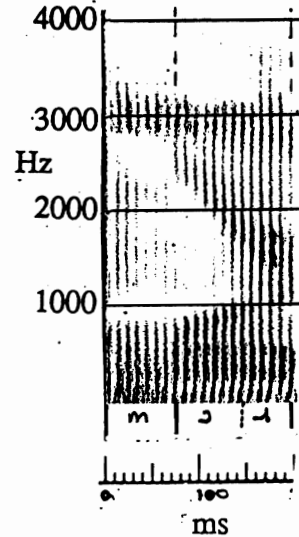
The obvious question to ask is whether there are indeed two segments in these cases. In the case of diphthongs, the vowel and glide are arguably in some sense a single segment and both in the nucleus of the syllable. It is thus not surprising that nasalization in these cases should occur throughout the "sequence". The observed pattern in (27biii) is more surprising, since here we see a contrast between /Vr/ sequences (27biii & 27aiii) based only on vowel quality. Upon closer inspection, an interesting difference emerges between the /r/ in these two cases, as can be seen in the spectrograms of these two forms, in (28).

(28) Spectrograms of *near* /nir/ and *more* /mɔr/

a.



b.

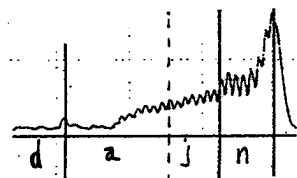


The /r/ in /nir/ appears to be a separate segment, as can be seen in (28a) at 150-220ms. There is a portion of 70ms during which the formants are r-like and stable. In contrast, in the case of the /r/ in /mɔr/ in (28b), there is a smooth change in formant structure throughout the vowel, but no portion that can be identified as a separate segment. In this case then, there is an r-colored vowel rather than a vowel-/r/ sequence. (In my own speech, I can feel this difference in the articulation of these forms: in the /nir/ case, there is a noticeable tongue movement in the production of the /r/; whereas in the /mɔr/ case, no such movement occurs between the vowel and /r/.) I assume that phonologically this difference is captured by both the vowel and /r/ occurring in the nucleus of the syllable in the /mɔr/ case (parallel to the diphthongs), but the vowel in the nucleus and the /r/ in the coda in the /nir/ case. The One Segment Principle must be sensitive to a level of representation at which /a/ and /ɔ^r/ function as single segments. (It should be noted that the observed difference between /nir/ and /mɔr/ for Speaker E-C was systematic for all tokens, but for Speaker E-F, some of the /mɔr/ tokens looked similar to /nir/ tokens. Interestingly these tokens also showed the steady state portion of the /r/, characteristic of the /nir/ tokens for both speakers; thus it seems to be the case that Speaker D-F has two alternate pronunciations of this form.)

In turning to the last pattern of expected long distance effects, VRN, we expect that here too the structure of the rime will affect the observed patterns. Representative examples are presented in (29).

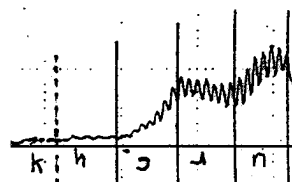
(29) Representative examples of VRN patterns

a. *dine* /daɪn/ [E-C 4]

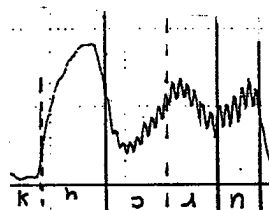


b. *corn* /kɔɹn/

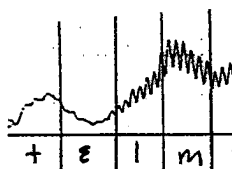
i. [E-C 2]



ii. [E-C 5]



c. *tell m(ore)* /tɛl\$ɪm(ɔɹ)/ [E-C 4]



In both (29a) /daɪn/ and (29b) /kɔɹn/, we see that there is nasalization from the onset or near the onset of the vowel, as expected if the glide or r-colored vowel function as a single unit. In (29b) /kɔɹn/ (and similarly in the form *kindness* /kaɪndnes/ not exemplified here), two distinct patterns are observed. In the first pattern (29bi), there is cline-like nasalization observed; in the second (29bii), there is an abrupt onset of nasalization toward the end of the oral stop. The existence of these two patterns follows from the optional application of the proposed rule of [+Spread Glottis] Nasalization. In (29c) /tɛl\$ɪm(ɔɹ)/, we observe some nasalization of the /l/, but not of the preceding vowel. This is as expected following the One Segment Principle. The effects on the /l/ are quite restricted in some of the tokens, due, perhaps, to a junctural effect. (The observed pattern of flow on *elm* /ɛlm/ is rather confusing, with some cases in which only the /l/ is nasalized, and others in which both the vowel and /l/ are. It may be the case that in some tokens, the /l/ becomes vocalic and functions as part of the nucleus. Further data would be needed to resolve this question.)

In summary, the NVR and VRN patterns are consistent with the One Segment Principle, with diphthongs and r-colored vowels functioning as single segments.

5.5.5. Conclusion

In this section, it was observed that long distance effects involving glides, liquids and vowels were much less pervasive than predicted. Although not without exception, it was argued that these effects were generally constrained by the One Segment Principle. A subtle difference in application of this principle was observed between cases where what might be characterized as two segments underlyingly function as a single unit with respect to this principle.

However these conclusions can only be taken as tentative, due to the variability and inconsistency in some of the forms. Additional tokens of these forms as well as additional forms of these patterns are needed to confirm the rather subtle patterns upon which these conclusions are based.

5.6. Effects involving [-continuant] consonants

We turn now to effects involving [-continuant] consonants. In the following discussion, we consider the behavior of both voiced and voiceless stops, exemplified by /d/ and /t/ respectively.

5.6.1. Predicted patterns

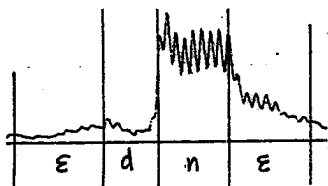
For the speakers of French and Sundanese studied, the behavior of voiceless and voiced stops was observed to be quite straightforward. Phonetically voiceless stops were always oral for their full duration in all contexts, whereas voiced stops were amenable to nasalization at their left edge in some contexts, but were always oral by their release. The facts in English turn out to be more complex due to certain allophonic rules, including possible deletions and Glottalization. Although the English data present apparent counter examples to the above generalizations, we will see that the observed patterns follow from phonological rules of allophony. We take as a starting point, the assumption that both voiced and voiceless stops are specified as [-nasal] at the output of the phonology.

5.6.2. The realization of /d/

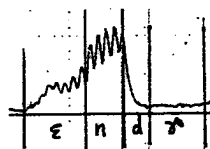
We consider first the behavior of /d/. Representative flow traces are presented in (30).

(30) DN and ND

a. *redneck* /rɛdnɛk/ [E-F 5]



b. *sender* /sɛndə/ [E-C 2]



c. *penny* /pɛni/ [E-C 3]



In (30a), we see an example of DN: during the oral closure, there is a significant portion with no nasal flow and then a rapid transition into the nasal portion, as predicted. (In this form for Speaker E-C, deletion of either the /d/ or /n/ was observed, so it does not illustrate the intended pattern.) In (30b), we see an example of (V)ND(V). The overall duration of the oral closure is

shorter, but there is still a distinct nasal portion followed by an oral portion. The brief oral portion is followed by a clear oral release, resulting in the following vowel being fully oral. The /d/ in this case is quite short, but we can see that it is indeed present by comparing with a VNV form such as *penny* /peni/, exemplified in (30c), where the overall oral closure is noticeably shorter. Average durations for these two patterns are presented in (31):

(31) Average duration measurements in ms for five tokens for Speaker E-C

appender	sender	penny
ϵ n d ∂ 85 43 26 73	ϵ n d ∂ 82 47 36 75	ϵ n i 86 55 96
n + d 69	n + d 82	n 55

In (31) we see that the average duration of the /n/ in the /nd/ forms is not appreciably shorter than that of the /n/ in the /n/ forms – 43ms or 47ms compared to 55ms. Additionally the combined average duration of /nd/ is longer – 69ms or 82ms compared to 55ms. (As noted before, many more tokens would be needed to determine the statistical significance of this difference.)

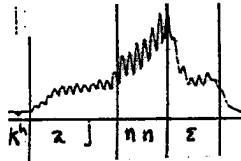
The observed pattern in (30b) is consistent with the view that both the nasal and oral stop receive targets for most of their duration, with the nasal having priority over the transition, if we also assume an independent timing model which accounts for the very short duration of both /n/ and /d/ in these cases.

This conclusion, however, is only a tentative one. Since the /d/ is very short, it is difficult to judge if the /d/ has a duration with an inherent target, which is quite brief due to the preceding nasal consonant controlling the transition, or whether it is really characterized by only a single point at its release, as predicted by Huffman (1989). One way to tease apart these two hypotheses would be to collect data which manipulated duration independently. The inherent target view predicts that in the case of longer /d/'s the transition should be the same, with a longer steady state portion; a point target at the voiced stop release predicts that the slope of the transition should differ.

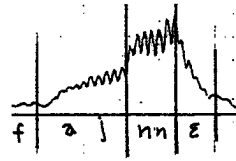
We turn now to NDC forms, where the outcome is quite different. As discussed above in §5.2.4., this is the context in which Selkirk (1972) describes a phonological rule of deletion: d — > Ø / N__C. As we will see, the data support the conclusion that such a rule has applied. There are three forms in the corpus where /d/-Deletion is predicted: *kindness* /kaɪndnes/, *send#t(wice)* /send\$t/ and *penned#t(wice)* /pend\$t/. Representative examples are presented in (32) along with minimally contrasting forms *fineness* /faɪnnes/ and *pen#t(wice)* /pen\$t/:

(32) Representative examples of NDC and NC

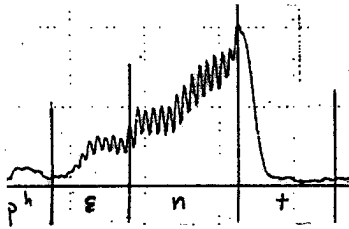
a. *kindness* /kaɪndnes/ [E-C 1]



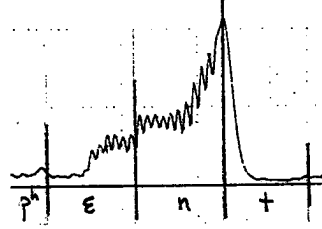
b. *fineness* /faɪnnes/ [E-C 5]



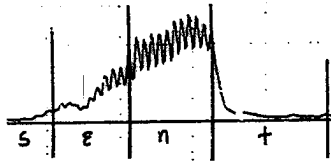
c.i. *penned#wice* /pend\$t/ [E-C 1]



d. *pen#wice* /pen\$t/ [E-C 5]



ii. *send#wice* /send\$t/ [E-C 1]



In the flow traces in (32a & c), there is no sign of a /d/. In (32a), /kaɪndnes/, there is a consistent level of nasal flow throughout the consonant sequence, comparable to that seen in (32b), /faɪnnes/, where a geminate nasal occurs. There is no dip in the nasal flow; nor is there anything even approximating an oral release. In (32c), the stop closure following the /n/ is voiceless (as can be seen in the audio signal, not presented here). This could be due to some kind of process of voicing assimilation of the /d/ to the following /t/, but as will be shown below, the timing facts support the view that the /d/ is deleted in these cases.

Consider first the timing of /kaɪndnes/ compared with /faɪnnes/, as summarized in (33).

(33) Average duration measurements in ms of five tokens each for Speaker E-C

kindness	fineness
aɪ ndn ε	aɪ nn ε
117 61 54	136 76 58

The average of the total duration of the /ndn/ in /kaɪndnes/ (61ms) is actually shorter than the average duration of the /nn/ sequence in /faɪnnes/ (76ms). This is taken as evidence of the fact that the /d/ is indeed deleted in a categorical manner in these cases. (The shorter duration for *kindness*, if statistically valid, may be due to its being a more common word than *fineness* and therefore,

stored in the speaker's lexicon as a single unit.) In none of the five tokens is there any trace of the /d/.

Consider now the average timing when the /d/ precedes a non-nasal consonant, in these examples a /t/, presented in (34).

(34) Average duration measurements in ms for Speaker E-C

penned-t(wice) 2 tokens	send-t(wice) 5 tokens	pen-t(wice) 5 tokens
ε n d-t 114 100 129	ε n d-t 102 130 122	ε n t 131 109 130

All five tokens of /send-t/ appear to have the /d/ deleted, whereas only two of the tokens of /pend-t/ do, which may be a word frequency effect, since *penned* is a rarer form. Only these two tokens were included in the average durations in (34). In (34) as above, we observe that the average durations of the underlying /d-t/ clusters (129ms in /pend-t/ and 122ms in /send-t/) are shorter than the average duration of the /t/ in /pen-t/ (130ms). Additionally, in all of these cases, the full duration of the /d-t/ is voiceless, in contrast to the cases where the /d/ is not deleted, where there is first a voiced portion. The timing facts and voicing facts together support the view that there is full deletion of the /d/ in these cases. Note that these cases of /pen+d#t/ appear to be homophonous with /pen#t/. It would be interesting to see if perceptual studies support this conclusion.

We conclude that there is a phonological rule of /d/-Deletion – as evidenced by its categorial results – that operates (at least) in the environment of a preceding /n/ and a following alveolar stop. Note that this rule is optional. For Speaker E-C, it applies in most cases where the environment is met, but for Speaker E-F, it applies less regularly. The application of this rule is presumably sensitive to speech rate and phonological phrasing.

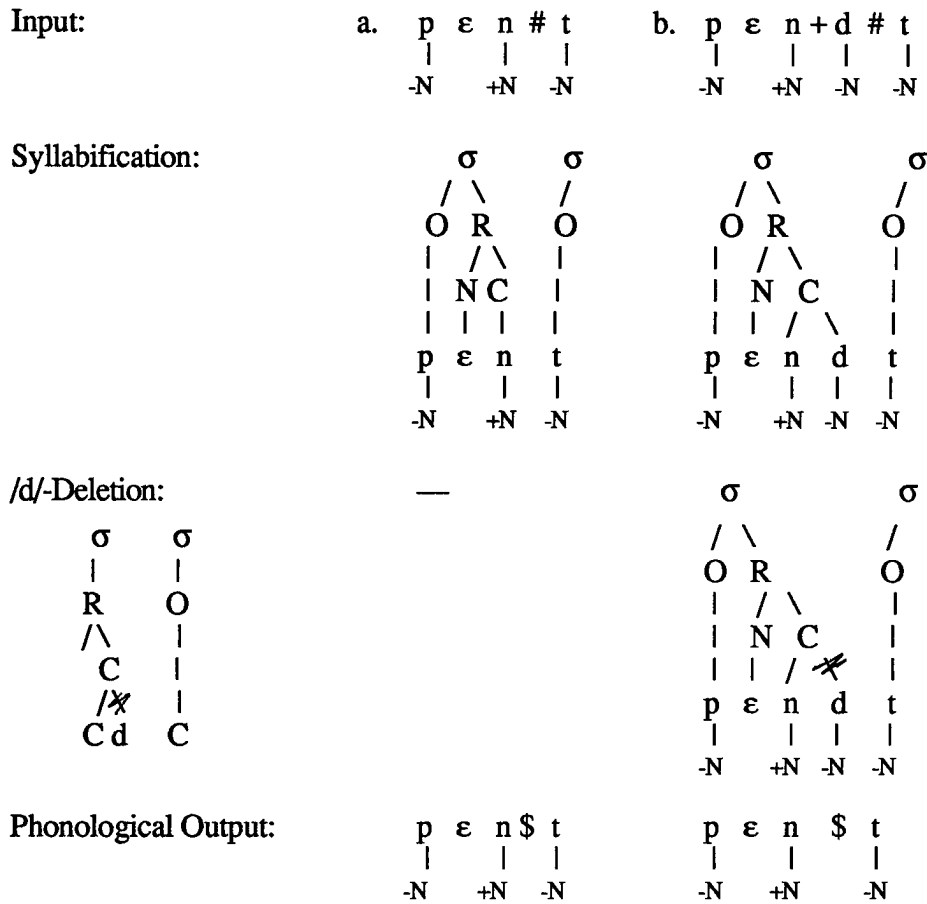
Additional data would be needed to determine how systematically this rule applies with other right environments. For Speaker E-F, /d/-Deletion applies before /t/ but not /k/.

The rule of /d/-Deletion must be represented in terms of syllable structure as stated in (35).

(35) /d/-Deletion	σ	σ	applies optionally
	R	O	
	∧		
	C		
	/*		
	C d C		

A /d/ on the right side of a branching coda preceding another consonant is optionally deleted (with possible segmental conditions on the onset of the following syllable, such that it must be homorganic). Phonological derivations of *pen#t* and *penned#t* are presented in (36):

(36) Sample derivations



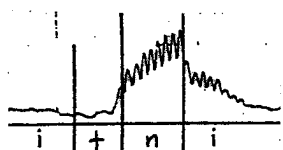
In (36), the inputs are as shown; syllabification takes place. Then the rule of /d/-Deletion applies in (36b), resulting in (36a & b) being homophonous, yielding the phonetic patterns, seen above in (32c.i. and 32d).

5.6.3. The realization of /t/

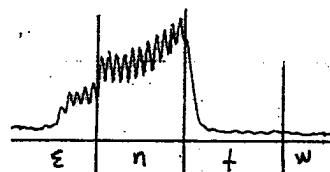
We turn now to the realization of /t/ when adjacent to a nasal consonant. As discussed above in §5.6.1, a voiceless stop either preceding or following a nasal consonant is predicted to be oral for most of its duration. In certain environments, /t/'s behavior is as predicted. In these cases, the /t/ is oral throughout most of its duration as shown in the examples of TN and NT patterns presented in (37).

(37) Representative examples of TN and NT

a. *(repea)t need /t#nid/ [E-C 2]*



b. *den tw(ice) /den#tw/ [E-C 5]*



In (37a) we see an example of a /t/ preceding a nasal consonant. Here, as predicted, the /t/ is oral, until the onset of voicing, which is simultaneous with the onset of nasal flow. In (37b), we see an example of a /t/ following a nasal consonant. Here too, the /t/ is oral for most of its duration.

Yet this is not always how /t/ behaves. As discussed above, there are three phonological rules in English expected to affect such sequences: Nasal Deletion, Glottalization, and /t/-Deletion. Each of these plays a role in the realization of NT and TN sequences. We consider the effects of these three rules in turn.

5.6.4. Nasal Deletion

We consider first the rule of Nasal Deletion, as described in §5.2.2,

$$\left[\begin{array}{c} C \\ +nasal \end{array} \right] \rightarrow \emptyset / _ \left[\begin{array}{c} -cont \\ -voice \end{array} \right] \$.$$

5.6.4.1. Predicted patterns

This rule is expected to result in complete deletion of the nasal consonant. Yet it is not the case that a nasal consonant deleted by such a rule completely loses its nasal effect: *sent* /sɛnt/ does not become homophonous with *set* /set/, since the preceding vowel is nasalized in the former case. There are two issues that we need to consider: (1) the source of this nasalization and (2) the status of a "short nasal".

(1) Typically the nasalization of the preceding vowel in such cases is accounted for by a general rule of Anticipatory Nasalization, assumed to precede Nasal Deletion. But it was argued above that no such general rule of Anticipatory Nasalization exists in English (at least not for the two speakers under investigation here). Rather, the nasalization of the preceding vowel must result directly from the deletion of the nasal consonant. The most straightforward way to achieve this is to assume that in the deletion of the nasal consonant, the [+nasal] specification is left floating and that it relinks to the preceding vowel. In such cases, we would then expect a plateau-like pattern of nasalization on the vowel (such as seen during a nasal vowel in French or Sundanese), rather than a cline-like pattern otherwise predicted.

(2) As will be seen below, there appears to be a continuum from a full nasal consonant, to a shortened nasal consonant, to deletion. We need to consider at what point the nasal consonant has indeed been deleted. If the nasal consonant is deleted and the [+nasal] specification relinked to the preceding vowel, we expect to see a transition between the [+nasal] specification of the vowel and the [-nasal] specification of the following /t/. Based on our observations from the speakers of French and our proposed priority statements, we would expect the transition from [+nasal] to [-nasal] to occur during the beginning of the stop. This would have the effect of a brief portion of the stop (20-30 ms) being nasalized and perhaps (erroneously) appearing to be a brief nasal consonant. But the character of this "short nasal" should be different from a true nasal, in that we expect to see decreasing nasal flow, not a stable portion of flow. The observed pattern should be similar to the transition in French in a form such as *bon thon* /bɔ̃tɔ̃/ discussed in Chapter 4 or to the transition observed above in (37b). In studying the data, we need to distinguish between a very

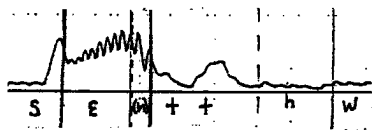
brief nasal consonant of 20-30 ms, the result of a transition, and a longer nasal consonant, indicating that the nasal consonant has not actually been deleted.

5.6.4.2. The cases

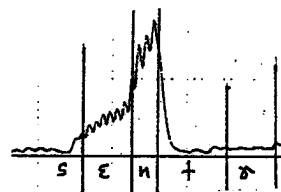
There are four forms in the data set which potentially meet the environment of Nasal Deletion: *sent-t(wice)* /sɛnt#t/, *pent-t(wice)* /pɛnt#t/, *center* /sɛntə-/ and *repenter* /rɛpɛntə-/. (We return below to the form *faintness* /feɪntnes/ also potentially affected by this rule.) Consider representative examples of these four forms for Speaker E-C, in (38).

(38) Representative examples of NT for Speaker E-C

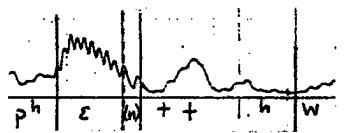
a. *sent-t(wice)* /sɛnt#t/ [E-C 1]



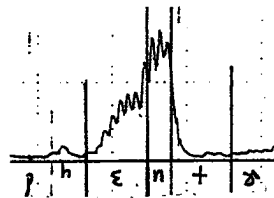
b. *center* /sɛntə-/ [E-C 1]



c. *pent-t(wice)* /pɛnt#t/ [E-C 3]



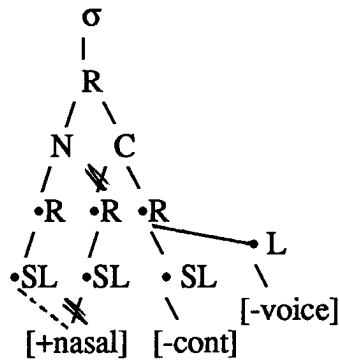
d. *repenter* /rɛpɛntə-/ [E-C 1]



In (38a & c), we see examples that fit our expectations for the output of Nasal Deletion. The pattern of flow on the preceding vowel is quite plateau-like, consistent with its being specified as [+nasal]; and although there is a short nasal consonant, its duration and falling character of the nasal flow are consistent with its being a transition. The patterns seen in (38b & d) are quite different. Here, the nasal is short, but not transitional in the same way: the highest amplitude of flow is observed at the end of the nasal portion. Additionally, the preceding vowel does not appear to be fully nasalized, but is nasalized in a cline-like manner. (In some of the tokens of *repenter* /rɛpɛntə-/, there is full nasalization of the vowel, but this could be a result of the application of [+Spread Glottis] Nasalization.) We conclude then that the rule of Nasal Deletion has applied in the former, but not the latter cases. These cases differ primarily in syllable structure. In (38a & c), both the nasal and following oral stop are in the coda of the same syllable, whereas in (38b & d) the /t/ is ambisyllabic, also forming the onset of the following syllable.

I propose therefore a rule of Nasal Deletion, with concomitant relinking of the [+nasal] specification to the preceding vowel, limited to the environment where the following /t/ is in syllable final position. (I have written the rule generally to include other places of articulation. There may be an additional condition that the deletion only occurs if the nasal oral stop sequence is homorganic. But we have no data in the present corpus which addresses these two points.)

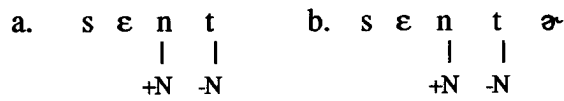
(39) Nasal Deletion and Relinking



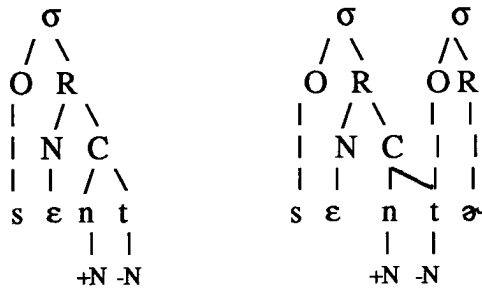
A nasal consonant is deleted when preceding a tautosyllabic voiceless stop. The [+nasal] specification is left floating and relinks to the preceding vowel. Sample phonological derivations of *sent* and *center*, with Nasal Deletion applying in the former, but not the latter case, are presented in (40).

(40) Sample derivations

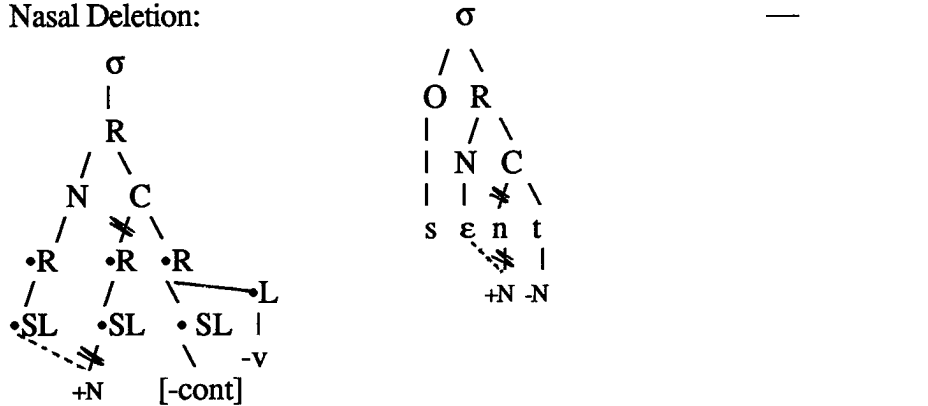
Input:



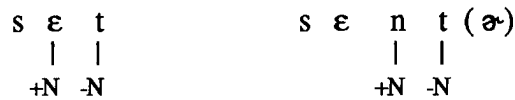
Syllabification:



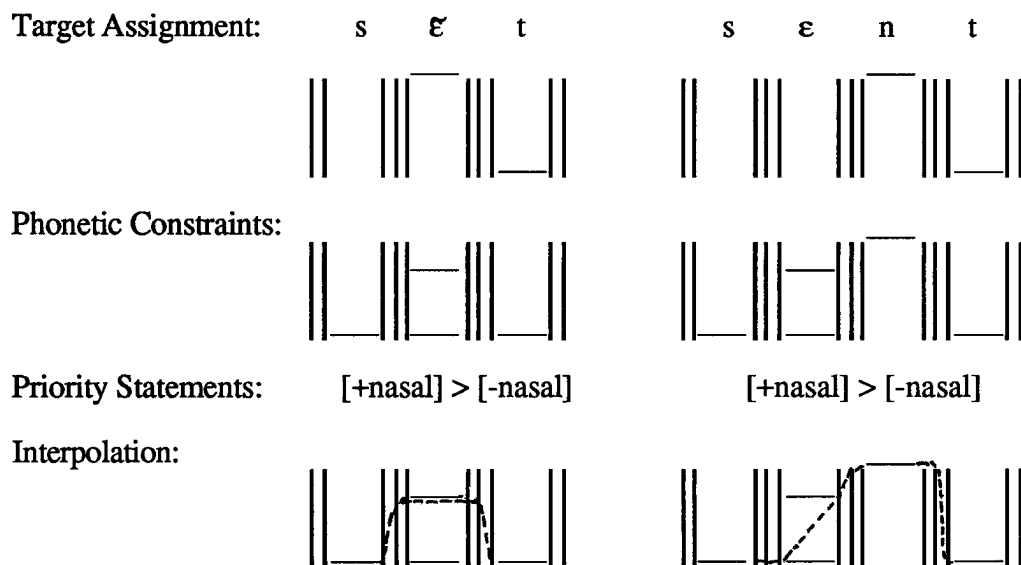
Nasal Deletion:



Phonological Output:



Phonetic Implementation:



In (40a), the environment for Nasal Deletion is met. The nasal consonant is deleted and the [+nasal] specification relinks to the preceding vowel. When the phonological specifications are mapped to the targets, the vowel receives a nasal target. (I assume that /s/ is subject to a phonetic constraint that it must be phonetically oral due to its voicelessness.) In its implementation then, the vowel surfaces with a plateau-like pattern of nasalization. In (40b) Nasal Deletion does not apply. The nasal consonant remains at the output of the phonology and the vowel remains unspecified. In the phonetic implementation, the vowel then receives a cline-like pattern of nasalization.

Before concluding the discussion of this rule, there are some further issues that need to be considered, relating to its application.

Nasal Deletion applies in the data for Speaker E-C, but does not appear to apply for Speaker E-F. The observed data for Speaker E-F are quite different from that seen for Speaker E-C. For Speaker E-F, although there is shortening of the /n/ in *sent* and *pent*, there is no clear evidence of a categorial process of Nasal Deletion. The nasal consonants, although very short, are, nevertheless, longer than we would expect for a transition (44ms in /pent#t/ and 51ms in /sent#t/, average for five tokens each). Additionally, in the tokens of *sent* there does not appear to be full nasalization of the vowel, except perhaps in token E-F 2. (Full nasalization in some of the tokens of *pent* may well be due to the rule of [+Spread Glottis] Nasalization.) We must therefore conclude that the application of the rule of Nasal Deletion is either affected by individual speaker differences, or is optional (affected by speech rate and style).

The conditioning environment of this rule may also differ between speakers or be based on speech rate and style. For Speaker E-C, this rule applies if the /nt/ sequence is tautosyllabic, but not if the /t/ is also ambisyllabic. Yet it appears to be the case that, for at least some speakers or in some speech styles (perhaps more casual speech than that elicited in the present study), this rule applies if the voiceless stop is ambisyllabic as well. Zue and Laferriere (1979), in their extensive phonetic study of medial /d/ and /t/ in English, observe nasal deletion in 18% of the relevant cases. Due to the structure of their corpus, the relevant forms were of the form VntV, presumably

ambisyllabic. Additionally Kahn (1976) notes an interesting relationship between Flapping and Nasal Deletion. Flapping is argued by Kahn to occur in the environment of a preceding [-consonantal] segment. Flapping in forms of the underlying shape VntV can occur if and only if the nasal consonant has previously been deleted by Nasal Deletion, thereby setting up the environment for Flapping, e.g. *center* /sentə/ [sɛ̃rə]. Although this pronunciation was not attested in the present corpus, it appears that such pronunciations are possible for some speakers in some speech styles.

We have proposed a phonological (categorical) rule of Nasal Deletion, applying for some speakers in some cases. However, this rule is in a sense the endpoint along a continuum of nasal shortening. Since the process of nasal shortening is quantitative, it is presumably part of the phonetics. It may seem odd that the results of part of the continuum are phonological while part are phonetic, but this does indeed appear to be the case. This kind of continuum, where the effects at the endpoint are the result of a phonological rule, is exactly what we would expect to result from the process of phonologization (see Hyman 1976). One part of a phonetic process becomes relevant to the phonology and becomes phonologized, but the phonetic effects remain in other environments.

Finally, even in cases where there is only nasal shortening but not deletion, there may still be a perception that the nasal consonant has been deleted (see Malécot 1960). Why should this be the case? As discussed below, undeleted nasal consonants in this environment can be glottalized. I believe that the perception of deletion is strongly influenced by this glottalization of the nasal consonant. Glottalization of /n/ has a marked weakening effect. An [n'] has a much lower level of nasal airflow than a non-glottalized /n/. Such low flow might well result in the perception of deletion. Since glottalization of /n/ occurs quite generally for both of the speakers in the study, I conclude that it is the weakening of the nasal consonant that results in the perception of Nasal Deletion in the cases where Nasal Deletion has not applied.

5.6.5. Glottalization and its effect on the realization of the feature Nasal

We turn now to Glottalization and its interaction with the rules of Nasal Deletion and /t/-Deletion.

5.6.5.1. The patterning of Glottalization

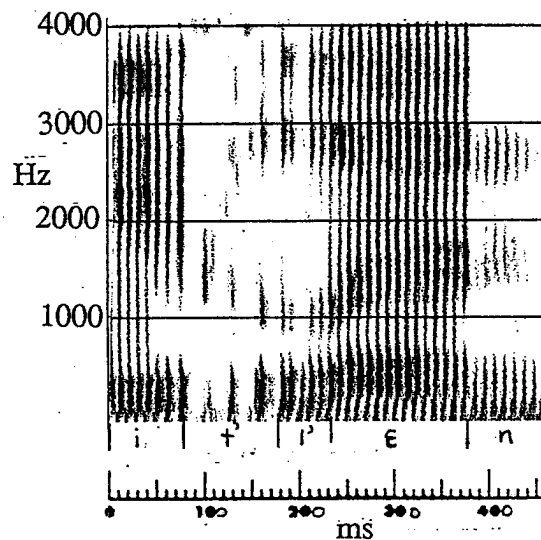
Let us consider how and when Glottalization applies. As discussed in §5.2.3, both Selkirk and Kahn describe a phonological rule of Glottalization in English, by which a syllable final /t/ following a [-consonantal] or [+sonorant] segment (depending on whose description) becomes glottalized; i.e. [+constricted glottis].

Glottalization occurred quite systematically for Speaker E-C, and less regularly for Speaker E-F when /t/ was syllable-final (and not ambisyllabic), preceded by a vowel. Most of the example in the corpus were of the /t/ of *repeat* /rəpit/ in the frame sentence. (Speaker E-F often had a released /t/ in *repeat* /rəpit/). In these cases, the /t/ was syllable final following a [-consonantal] segment, an environment in which Glottalization was predicted by both Selkirk and Kahn.

Glottalization also occurred for both speakers, in at least some tokens, in *sent* /sɛnt/, *pent* /pɛnt/ and *faintness* /feɪntnɛs/. This means that for Speaker E-F, Glottalization occurred after a nasal consonant, since, as noted above, the nasal consonant was not deleted. It appears that, at least for Speaker E-F, Glottalization can occur following a nasal consonant as well as a [-consonantal] segment, supporting Selkirk's characterization of the left environment as [+sonorant] over Kahn's characterization as [-consonantal]. There was characteristically glottalization of the /t/ in such forms as *sent* /sɛnt/ [tʰ], but not *center* /sɛntə/ where the /t/ is assumed to be ambisyllabic.

Glottalization shows up in the audio signal (either the waveform or spectrogram) as irregular vocal pulses. They are seen at the end of a preceding vowel or during a following sonorant, as discussed below. The irregular vocal cord pulses are also reflected in some cases in the nasal flow trace, since such low frequency pulses are not filtered out by the low pass filter designed to remove regular voicing pulses. A spectrogram of a glottalized /t/ is presented in (41).

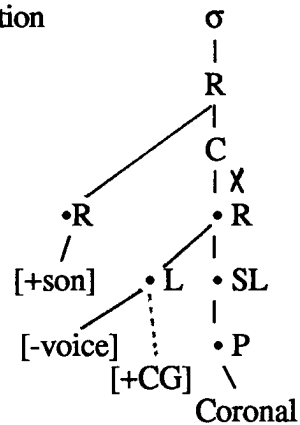
(41) Spectrogram of glottalized /t/ *repeat Len* /rɛpɪtʰɛn/ [E-C 1]



Here we observe irregular vocal pulses during the /t/ (80 - 180ms). In some cases, slight glottalization occurs at the end of the segment preceding a glottalized /t/, due presumably to the effects of phonetic interpolation. (This does not appear in the particular token presented in (41).) There is also glottalization of the following /l/ (180 - 230 ms), a point that we return to in a moment.

These data support the conclusion that there is a phonological rule of Glottalization in English, but its application is optional. In (42) the rule of Glottalization is formulated using the feature hierarchy. I assume that /t/ is unspecified for the feature Constricted Glottis; that the effect of the rule is to add a [+constricted glottis] (+CG) specification; and that the rule applies when /t/ is in syllable final position, following a [+sonorant] specification.

(42) Glottalization



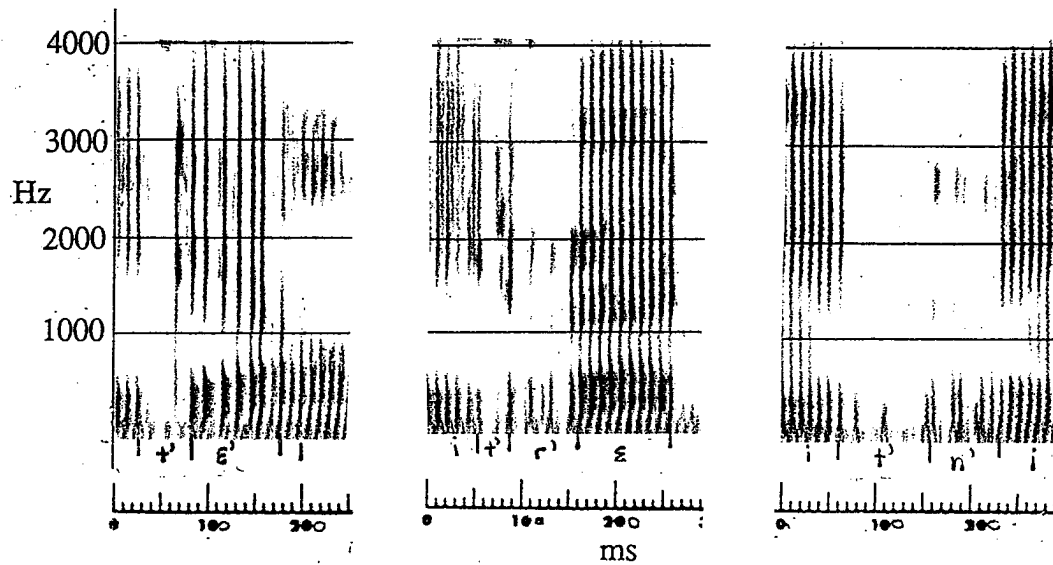
A syllable final /t/ following a [+sonorant] segment becomes [+constricted glottis]. As seen in the /l/ above in (41), a sonorant following a glottalized /t/ may be glottalized as well, in a quite categorial fashion. This is true for a following /r, n, l/ or vowel, as exemplified in the spectrograms in (43):

(43) Examples of glottalized sonorants

a. (repea)t Elmer
/t#ɛlmə/ [E-C 1]

b. (repea)t redneck
/t#rɛdnɛk/ [E-C 1]

c. (repea)t neo
/t#niə/ [E-C 1]



In (43a) we see glottalization of a vowel following a glottalized /t/. The vowel is glottalized for its full duration, but the following /l/ is not affected. In (43b) a following /r/ is fully glottalized, but not the subsequent vowel. In (43c) a following /n/ is glottalized, but again not the following segment. In each case the immediately following [+sonorant] segment is glottalized throughout its duration, but the subsequent segment is not affected, even if it is [+sonorant]. To account for this glottalization of a following segment, I propose a rule of Glottal Spread, whereby a [+Constricted Glottis] spreads to the right to a following [+sonorant] segment, as shown in (44).

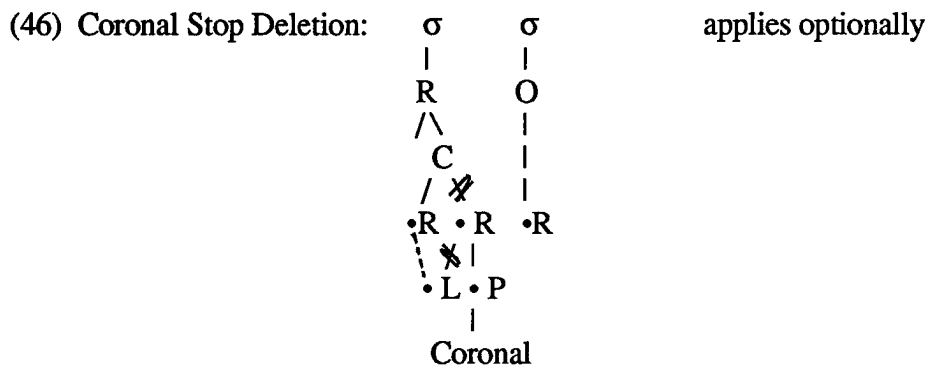
What we observe in (45a & c) is cline-like nasalization both preceding and following the consonant sequence and nasalization and glottalization throughout the oral closure. When compared with the duration of the oral closure of /nn/ in (45b & d), we see that the oral closure of /ntn/ is comparable. The average durations for five tokens of these sequences for both speakers are close, but inconclusive: Speaker E-C: /ntn/ 89ms, /nn/ 77ms; Speaker E-F: /ntn/ 135ms, /nn/ 110ms.

The most straightforward analysis of the observed output in *faintness* /fejnt+nes/ is that /t/-Deletion has applied.

To account for the fact that it is /t/-Deletion, not Nasal Deletion, that both speakers apply in the form *faintness* /fejnt+nes/, /t/-Deletion must be ordered before Nasal Deletion. This leaves us with the question of why /t/-Deletion does not apply in forms such as *sent* /sent/ and *pent* /pent/. As Selkirk (1972, p. 193) notes, the application of /t/-Deletion is conditioned by the strength of the boundary and is least likely across a word boundary where the two words are not part of a close syntactic phrase, as is the case in *sent* /sent/ and *pent* /pent/.

Although in terms of timing, /t/ appears to have been deleted, the effects of glottalization still remain, exactly as described by Selkirk. In order to account for the observed glottalization, the rule of Glottalization must precede /t/-Deletion and Glottal Spread. The observed effects can be represented in a straightforward way within current feature hierarchical representations. I assume that when the Root Node of /t/ is delinked, the Laryngeal Node is left floating. This then relinks to an adjacent segment. Under this view, the Laryngeal Node would be argued to have the same kind of stability properties as observed by Steriade (1982). Additionally, Glottal Spread must apply, spreading [+constricted glottis] to the following nasal consonant as well.

If we assume that the laryngeal features are also left floating in /d/-Deletion, but that their relinking is vacuous (since the preceding [-consonantal] or [+nasal] context would independently be [+voice]), the only distinctive laryngeal specification of /d/, we can represent both /t/-Deletion and /d/-Deletion as a single rule, Coronal Stop Deletion, presented in (46).



A coronal stop, on the right side of a branching coda preceding another consonant, optionally deletes, resulting in its laryngeal node relinking to the preceding segment. Sample phonological derivations involving Glottalization and Coronal Stop Deletion are presented in (47):

(47) Sample Derivations

Input:

a. fejntnes
 | | |
 +N-N+N

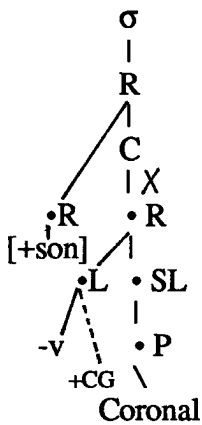
b. kajndnes
 | | | |
 -N +N-N+N

Syllabification:

σ σ
 / \ /
 O R O
 | / \ |
 | N C |
 | / \ / \ |
 f e j n t n
 | | | |
 +N -N+N

σ σ
 / \ /
 O R O
 | / \ |
 | N C |
 | / \ / \ |
 k a j n d n
 | | | |
 -N +N-N+N

Glottalization:



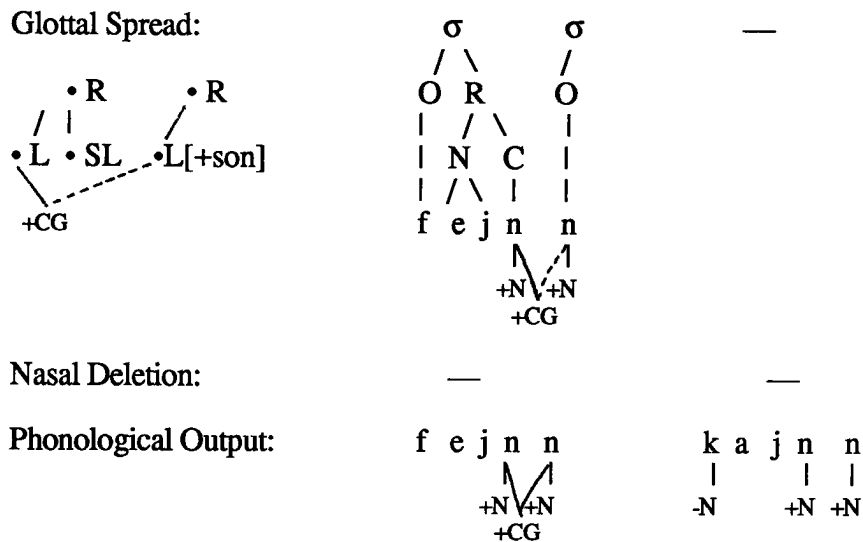
σ σ
 / \ /
 O R O
 | / \ |
 | N C |
 | / \ / \ |
 f e j n t n
 | | | |
 +N-N+N
 +CG

Coronal Stop Deletion:



σ σ
 / \ /
 O R O
 | / \ |
 | N C |
 | / \ / \ |
 f e j n t n
 | | | |
 +N-N+N
 +CG

σ σ
 / \ /
 O R O
 | / \ |
 | N C |
 | / \ / \ |
 k a j n d n
 | | | |
 -N +N-N+N



In (47a), Glottalization applies to the syllable final /t/. Then Coronal Stop Deletion applies, leaving the [+constricted glottis] specification to relink to the preceding nasal. Glottal Spread applies, spreading glottalization to the following nasal consonant, giving the phonological output as shown. In (47b), only Coronal Stop Deletion applies, deleting the /d/, giving the phonological output at shown. As noted above, Glottalization must be ordered before both Coronal Stop Deletion and Glottal Spread.

We account for the fact that Coronal Stop Deletion but not Nasal Deletion applies in (47a) by ordering Coronal Stop Deletion first. Nasal Deletion can apply only if /t/-Deletion fails to apply, as seen for Speaker E-C in the forms *sent* /sent/ and *pent* /pent/. It is predicted that in faster speech, Coronal Stop Deletion should be possible in such forms, resulting in an alternative pronunciation of [sen'] or [pen'].

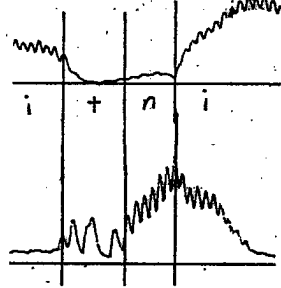
One possible complication of the analysis is that Glottalization is an optional rule. This predicts that there might be cases where Coronal Stop Deletion, but not Glottalization, applies in the case of a syllable final /t/. This would predict that there would be cases where the /t/ is deleted without glottalization of the adjacent nasals. Interestingly, of the five tokens of the form /fejnt+nɛs/ for Speaker E-C, one showed /t/-Deletion without Glottalization, lending support to the analysis.

5.6.6. Nasalization of glottalized /t/

The most striking consequence of Glottalization is that a glottalized /t/ becomes amenable to nasalization, an observation not preciously mentioned in the literature to my knowledge. We will see that this result follows from our proposed analysis. Consider an example of such a /t/ presented in (48), where both nasal and oral airflow are presented:

(48) Glottalized nasalized /t/ *repeat near* /rəpit nir/ [E-C 2]

oral



nasal

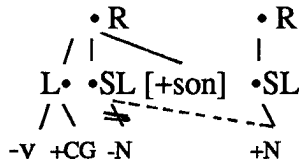
Here we see an example of glottalized /t/ which is also nasalized. Although there is some nasal flow during the /t/, we can see that there is still oral closure. This means that the segment is indeed a glottalized /t/, not a glottal stop. How is it possible that a voiceless oral stop should be amenable to nasalization? In the data from both French and Sundanese as well as other cases in English, /t/ has systematically been phonetically oral throughout most of its duration.

The answer, I believe, lies in an observation about glottalized /t/, made by Kahn (1976):

Now as pointed out in Section 1.2A, the glottalization of /t/ in words like *mat* deprives the alveolar obstruction of the opportunity of exercising its normal function of cutting off the airstream and holding back the resultant pressure build-up. Whether or not it is the glottalization of [t'] that is the primary cause of the absence of pressure build-up, the fact remains that if we follow our definition of sonority strictly, the [t'] of *mat* is [+sonorant]. (pp. 100-101)

Concomitant with the [+constricted glottis] specification, then, is a [+sonorant] specification. Since the glottalized /t/ is a sonorant, there is no pressure build up behind the oral constriction. Thus there is no reason to enforce a [-nasal] specification for the /t/. Such /t/s can, in effect, become glottalized nasalized /t/s, or in point of fact glottalized /n/s, by the spreading of a following [+nasal] specification. I propose the following rule of Sonorant Nasal Spread.

(49) Sonorant Nasal Spread applied optionally

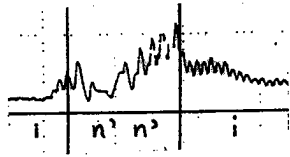


A [+nasal] specification may spread to a preceding glottalized oral stop, delinking its [-nasal] specification. This results in an [n'n] sequence, or, if Glottal Spread also applies to the following nasal, an [n'n'] sequence. Such [n'n'] sequences look very similar to the [n'n'] sequences in *faintness* /feɪntnes/ that arise due to Glottalization and Coronal Stop Deletion. Sonorant Nasal Spread must follow Glottalization, but is not crucially ordered with respect to Glottal Spread.

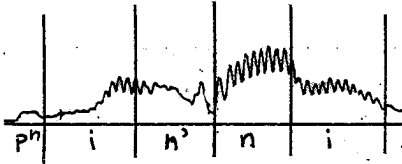
Additional support for this analysis comes from the fact that the vowel preceding a nasalized glottalized /t/ ([n']) may be partially nasalized, as expected for a vowel preceding a [+nasal] specification. Both [n'n'] and nasalized vowels preceding such sequences are exemplified in (50):

(50) Representative examples of [n'n'] and [ín'n']

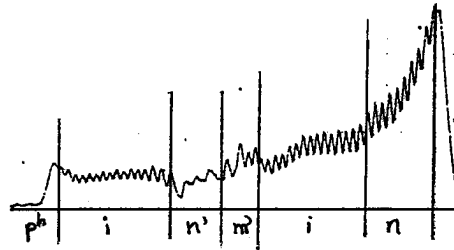
a. (repea)t knee /t#ni/ [E-C 1]



b. (re)peat neat /pit#nit/ [E-C 1]



c. (re)peat mean /pit#min/ [E-C 1]

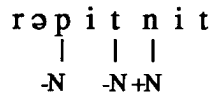


In (50a) *(repea)t knee* /t#ni/, we see an example of [n'n'], where both Glottal Spread and Sonorant Nasal Spread have applied, resulting in a surface glottalized nasal geminate. In (50b) we see that there can indeed be nasalization of a vowel preceding a glottalized nasalized /t/, expected only if the /t/ is [+nasal]. This pattern is consistent with patterns seen above due to phonetic interpolation throughout the duration of the vowel. In (50c), we see an additional example of nasalization of a preceding vowel, but this case is more startling, as there is full nasalization of the preceding vowel in a plateau-like manner. But if we consider the preceding context, [p^h], we realize that this pattern of nasalization may well have resulted from the application of [+Spread Glottis] Nasalization. (Note that the phonetic anticipatory nasalization is not as systematic in these cases as in other cases of a vowel preceding a [+nasal] specification in English, discussed above in §5.4. I assume that this is due to the effects of glottalization on the phonetic realization of nasalization.)

A derivation of *(re)peat neat* /pit#nit/ [ín'n'] is presented in (51):

(51) Sample derivation

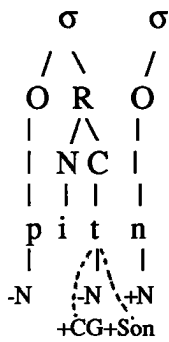
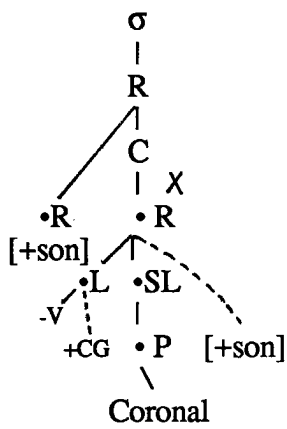
Input:



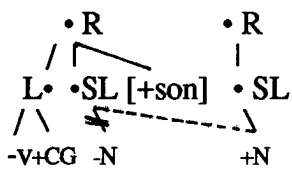
Syllabification:



Glottalization:



Sonorant Nasal Spread:



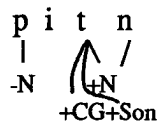
Glottal Spread:

—

[+Spread Glottis] Nasalization:

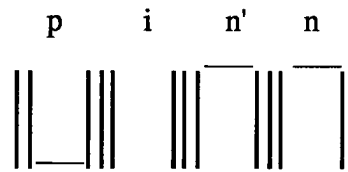
—

Phonological Output:

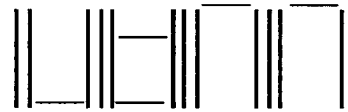


Phonetic Implementation:

Target Assignment:



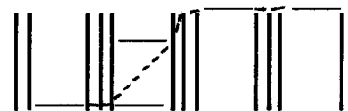
Phonetic Constraints:



Priority Statements:

NA

Interpolation:



In (51), first Glottalization applies. This results in the assignment of a [+constricted glottis] specification to the syllable final /t/, with the concomitant change to [+sonorant]. This sets up the environment for Sonorant Nasal Spread. Although the environments of both Glottal Spread and [+Spread Glottis] Nasalization are met, both of these rules are optional and neither one applies in this form. We thus have the phonological output as shown. When the feature specifications are mapped to targets, both the [n'] and [n] receive nasal targets. The vowel /i/ receives a transitional amount of nasalization through phonetic implementation. In addition, further effects of glottalization on nasality occur, but are not accounted for in this derivation.

5.6.7. Conclusion

In this section, several phonological rules affecting the realization of stops in English have been proposed. The only rule affecting /d/ is Coronal Stop Deletion. The situation for /t/ is appreciably more complex, as the optional glottalization of syllable final /t/ potentially triggers other rules, including Glottal Spread and Sonorant Nasal Spread. In addition, either Nasal Deletion or Coronal Stop Deletion may apply in the case of /nt\$/ sequences. The most striking observation is that glottalized /t/ may actually be amenable to nasalization (by the rule of Sonorant Nasal Spread), since oral pressure build-up is not necessary.

The situation with these rules is somewhat complex, as most of these rules were seen to apply optionally. In all likelihood speech rate and style and phonological phrasing are at least partially responsible for this "optionality". Further study which systematically studies speech rate would be illuminating.

5.7. Role of variability

In the English data, we have seen a considerable range of phenomena. Much of it is predictable from phonological context (either segmental or structural) and in that sense is not

variability as defined here. Yet there remains quite a range of surface forms which are not systematic or predictable. Within the five tokens of a particular form for a given speaker such variability is observed. In particular, there is variability of timing of onset and offset of nasalization with vowels and [+continuant] consonants, the segments unspecified for Nasal. In effect, then, the range of phenomena consists of allophony and phonetic variability together.

Variability occurs precisely where it does not "matter", in cases where there is no possible contrast. We expect that phonologically unspecified segments may be variable in their realization of nasalization. Onset or offset of nasalization may start within a range of time. In other words, a phonological system which is less constrained can result in more variability (Lindblom 1983, Manuel and Krakow 1984), but will not necessarily result in more of a particular property, in this case, nasalization.

Under this view, variability is expected when neither the phonology nor the phonetics imposes constraints. This is expected in cases where segments are unspecified leaving the phonology and have either weak or no phonetic constraints. This includes vowels and [+continuant] consonants which remain unspecified at the output of the phonology, since these are either unconstrained or only weakly constrained by the phonetics. Both phonetic underspecification and wide windows predict variability.

Of the three languages investigated in this study, English would be expected to exhibit the most variability, since most vowels and [+continuant] consonants remain unspecified at the output of the phonology. We have observed that there is indeed more variability in the data of the two English speakers than for the speakers of either French or Sundanese, but it should also be noted that there may well be speaker differences in degree of variability.

Sometimes the output of the phonology appears to result in variable effects, such as the realization of /nt/ and /nd/ clusters in English. But it was argued above that such differences in realization are a consequence of the application or non-application of optional phonological rules. If a phonological rule does not apply, this may result in variable phonetic behavior, since there may be underspecification leaving the phonology. A distinction is drawn here between optional phonological rules and phonetic variability. An optional rule either does or does not apply in a categorial manner.

5.8. Other recent studies

In this section, we consider the implications of two recent discussions of nasalization in English: Vaissière's (1988) analysis of velum movement in English, based on x-ray microbeam data; and Boyce et al. (1988)'s study using the Velotrace, a mechanical device for tracking velum movement.

5.8.1. Vaissière (1988)

Vaissière presents x-ray microbeam data of velum movement from two speakers of English. The microbeam continuously tracks a pellet placed in the nasal passage, resting on the velum halfway between the hard palate and the uvula, as an indicator of velum position. This velum position does not, however, indicate whether the velum is opened or closed. This makes relating

these movements to an abstract phonological system difficult, since not all movements are equal. It is well known that velum position is different for different vowel heights and qualities; thus the threshold for actual velum opening will differ for different segments and in different contexts. But, as argued in Chapter 4, the point at which the velum actually opens (or closes) is an important threshold, since only at that point is there perceptible nasalization (or lack thereof). Ultimately we want to be able to model systematically the rules that account for all such movement, but these must be studied in light of their perceptual relevance as well.

The data consist of several sentences each containing many nasal consonants. Systematic phonological analysis of the data presented is difficult, since complete transcription is not provided. It is difficult to know what the actual pronunciation was in certain cases, e.g. whether forms ending in /ənt/ were pronounced as schwa-nasal sequences, with a syllabic nasal, or with the nasal partially or completely effaced.

Based on the data, Vaissière undertakes to provide specific rules to account for the observed patterns of velum movement. She presents separate analyses for each of the speakers, whom she says use very different strategies of velum control. Both analyses are quite complex and require several (different) rules each. (It is not clear if multiple repetitions of the sentences were collected, thus it is not possible to determine to what degree these differences are truly interspeaker differences.) The complexity of and marked difference between the two analyses is somewhat perturbing.

It would be interesting to consider whether our analysis, involving very different assumptions, but many fewer rules, would yield a satisfactory account of Vaissière's data. For Speaker A, some of the data (three sentence fragments) are presented with the speech waveform envelope and for these, I have undertaken a rough segmentation.

Based on these data some preliminary comparisons with our analysis can be made. The data overall seem quite consistent with the patterns observed in the present study. First, Vaissière notes that "By careful examination of individual time functions of velum movement, we could not find any evidence of an inherent velum position for the vowels (V)." (p. 127). This is consistent with the conclusion in the present study that vowels are phonologically unspecified for the feature Nasal.

Additionally, there are ways in which the data are compatible with the present data, that are actually not accounted for by Vaissière's analysis.

One area in which her modeled output and the actual data differ is in cases of NVN, where she expects constant velum position (or lowering) but there is often a slight rise. This is similar to the observed rise noted by Kent et al. (1974), accounted for by Keating's windows and incorporated into the theory of phonetic constraints proposed here.

Vaissière assumes that for Speaker A, it is movements, not steady states, that are basic to phonetic implementation. (However for her Speaker B, both are required). She postulates that there is one fixed lowering slope and two raising slopes. Yet when her modeling of the data (i.e. Figure 12, p. 134) is examined, we see that the actual slopes are quite variable and do not consistently match her modeled ones. In (52), the total number of velum gestures for each sentence from Vaissière's Figure 12 are broken down by those which I have impressionistically interpreted as closely matching the predicted velocities and those which do not.

(52) Accuracy of modeling of velocity of velum lowering and raising for three sentences, presented by Vaissière (1988, Figure 12, p. 134)

Sentence #	<u>Lowering</u>			<u>Raising</u>		
	<u>accurate</u>	<u>not accurate</u>	<u>ratio</u>	<u>accurate</u>	<u>not accurate</u>	<u>ratio</u>
1	3	4	.43	5	1	.83
2	2	3	.4	3	1	.75
3	3	3	.5	4	2	.67
Totals	8	10	.44	12	4	.75

Overall	<u>accurate</u>	<u>not accurate</u>	<u>ratio</u>
	20	14	.59

As seen in (52), overall, including all the lowering and raising gestures, in 59% of the cases, the modeled slopes closely approximate the actual observed slopes. The modeled raising velum gestures are more accurate (75%) than the lowering ones (44%), due perhaps to the fact that two different raising gestures were proposed. Overall the slopes of lowering and raising of the velum show a much wider range of patterns than predicted by Vaissière's model and at a minimum the number of possible slopes must be increased. But additionally, looking at Vaissière's data, it is not obvious that it is movement rather than steady states that should be directly modeled, as there are significant plateaus, consistent with a steady state analysis.

Vaissière attempts to model directly all aspects of observed velum movement. This approach conflates effects from several different possible sources: phonology (categorical effects), phonetics (more gradient effects) and non-linguistic mechanical effects. This conflation results in a complex set of rules and the introduction of certain ad-hoc features, such as her feature Strong, which lack any clear phonological motivation.

Vaissière assumes that all oral consonants are [-nasal]. The consequence of Vaissière's assumption is that she has to propose specific rules to account for observed differences in the realizations of [-continuant] and [+continuant] consonants. In contrast, under our approach, such differences follow from the fact that [+continuant] consonants remain unspecified for Nasal.

In conclusion, Vaissière's data are not necessarily incompatible with a steady state type of analysis, but more systematic data are needed for her approach to be fully evaluated against mine.

5.8.2. Boyce et al. (1989)

Boyce et al. (1989) criticize the view of phonetic underspecification presented by Keating (1988a & b) and Cohn (1988). In looking at phonetic data on lip rounding and velum movement, Boyce et al. make the following two basic points. (1) The behavior of "supposed underspecified segments" can only be determined by examining these segments in different contexts. (2) The phonetics makes a contribution to the realization of "unspecified" segments. However, it is odd

that these are presented as criticisms, since both of these points are compatible with both Keating's and my work.

First, it is precisely through comparison of segments in different contexts that the contribution of any particular segment can be evaluated. This is the methodology used in Keating (1988a & b) and Cohn (1988), as well as in the present study, where segments in different contexts are compared in order to evaluate the contribution of a particular segment.

Second, Boyce et al. argue that the phonetic realization of phonologically unspecified spans does not result in completely smooth transitions, but that these "unspecified" segments make a contribution to their phonetic realization. The point is that the simplest view of phonetic underspecification is not tenable. Keating never claims that the only type of interpolation is strictly linear (although this would be the simplest), nor that unspecified segments make no phonetic contribution. Keating's (1988b) view of phonetic underspecification is basically programmatic and becomes a theory only when integrated with her other work, most notably her theory of windows (Keating 1988a). Keating observes that different segments make different degrees of contributions to the phonetic realization of a sequence. This is formally represented by each segment having a specific range of values associated with it. Boyce et al. note that these two papers, Keating (1988a and b), need to be integrated.

Boyce et al. seem to interpret two quite distinct mechanisms – interpolation through an unspecified span and feature copy (in current terminology, feature spreading) – as both being phonetic mechanisms. Under the type of view taken by Keating and myself, the former is a phonetic process, whereas the latter is a phonological one. As discussed in Chapter 4, it is an empirical question whether a phonological rule of feature spread has applied in any given case. Specification of the phonological output is a combination of the underlying specification and any specification resulting from the application of phonological rules. It is this phonological output that is mapped to the phonetics and the phonetics cannot distinguish between these two types of phonological specifications. But these phonological specifications are not arbitrary ones. The underlying specifications are motivated by contrast (and additionally under some views of underspecification theory, markedness) and the phonological rules are motivated by observed categorial results of such applications, as well as rule ordering.

It would be untenable to assume that the phonetics makes no contribution to the physical realization of speech. The fact that the phonetics plays a role (and not just a mechanical one) is clearly shown by the existence of language specific phonetic rules, independent from phonological feature specifications, as discussed in Chapter 1. The question is what is the nature of the phonetic contribution. Boyce et al. take an extreme position in arguing that for the velum, there must be precise articulatory configurations for unspecified segments. (Yet they do not explain how these relate to the phonological representation, nor how they are implemented.)

In the present study, I have incorporated and expanded Keating's proposed window constraints on interpolation. I have argued that phonetic requirements come into play precisely when segments are unspecified at the output of the phonology. Additionally to account for limits on predicted long distance effects, I have proposed that interpolation is constrained by the One Segment Principle. Thus, we see that two quite modest additions to the model account for the observed facts, while allowing us to maintain the insights of phonetic underspecification.

Let us consider more explicitly the velum data presented by Boyce et al. They present four forms showing velar displacement obtained with the Velotrace. (It is not clear if they are single tokens or averages of tokens.) These are of the shape *Its* ____ *sal again*, as summarized in (53).

(53) Forms for velum movement, presented by Boyce et al. (1989)

Its $\left. \begin{array}{l} \text{lansal} \\ \text{a lansal} \\ \text{say lansal} \\ \text{a lasal} \end{array} \right\} \text{ again}$

The first three forms have an increasing number of "unspecified segments" preceding a nasal consonant and the fourth is a control form with no nasal consonants. (The phonological specifications proposed are not motivated as such, although they are in keeping with a combination of the phonetic and phonological requirements made here. The phoneme /s/ is specified as [-nasal], /n/ is [+nasal] and vowels and /l/ are unspecified. The fact that /s/ is oral does not follow in any obvious sense from phonological specification resulting from contrast; rather it appears to be the case that /s/'s being oral is a phonetic, not a phonological, requirement.)

The claim is that as additional unspecified segments are added, if only linear interpolation is in effect, the transition between the [-nasal] specification and the [+nasal] specification should be stretched out. The forms presented show somewhat varying degrees of nasalization, argued to be due to intrinsic properties of the vowels. This is indeed likely to be the case, specially since the vowel immediately adjacent to the nasal consonant is /a/, the vowel with the greatest intrinsic nasalization (see Moll 1962, Ohala 1971). (In the present study, low vowels were avoided precisely for this reason.) Yet we are not given enough information to begin to sort out the nature of these effects.

In the case of a /slan/ sequence, velum movement starts at the end of the /s/, reaching a low position by the end of the /l/ and remaining low through the /a/ sequence. There is no indication at what point velum opening occurs, so it is not clear how these data compare with the data in the present study. But assuming that the opening of the velum occurs during the /l/ and the /a/ is indeed unspecified, their result is quite different from what is observed here for a /lVn/ sequence. Their pattern is actually more consistent with the assumption that /a/ is itself nasal. Such a specification could arise through a phonological rule that nasalizes low vowels before a nasal consonant. (There is some evidence that /a/'s, but not high vowels, are nasalized in a categorial manner when preceding a nasal consonant in Boisen 1986.) It is difficult to determine what is responsible, since no corresponding forms with high vowel are presented. A comparison of a set such as /lan, lin, tin/ would be useful.

I agree fully with the conclusion that there are effects not accounted for by the simplest view of phonetic underspecification, but such effects need to be more carefully teased apart than is done in the Boyce et al. study. The kinds of observations made by Boyce et al. need to be reconsidered in order to determine exactly what part of the observed phonetic output is due to contributions made by the phonology, the language specific phonetics, and more mechanical constraints and effects in articulatory movement. Only then can a complete model of all of these domains of activity be undertaken. As noted, throughout the present study there are extensive small effects

which are not accounted for by the proposed analysis. Some of these follow quite obviously from mechanical effects, e.g. linkage of the velum and tongue height, and some seem to be in the domain of phonetic variability. Here, I have not attempted to address the role of more mechanical effects, nor the behavior of actual muscle activity, since I believe that such questions cannot fruitfully be addressed until the relationship between phonology and phonetics is better understood.

5.9. Summary of the chapter

Overall, we have seen that the basic model proposed for the data from French accounts for the observed patterns of nasalization in the data from the speakers of English. It was argued that there is no general rule of Anticipatory Nasalization in English, but rather that the observed patterns of anticipatory nasalization result from the proposed model of phonetic implementation.

The one aspect of the English data that was not as predicted by the model proposed for French was the observed limits on long distance effects. The One Segment Principle was proposed to account for the fact that patterns of both anticipatory and carryover nasalization appear to be limited to approximately one segment, even in cases of a sequence of sounds expected to be amenable to nasalization. Additionally, several phonological rules were proposed to account for rather complex interactions that arise in the case of nasal-oral consonant sequences.

Zue and Lafferiére (1979) assume that Glottalization is a phonological process, whereas Anticipatory Vowel Nasalization and Nasal Deletion were concluded to be "low-level" phonetic rules. In our study, we reach the same conclusions about Glottalization and Anticipatory Vowel Nasalization respectively, whereas Nasal Deletion was concluded to be a phonological rule (applying in a more limited context than they discuss in their article). Zue and Lafferiére draw their conclusions based on the regularity of application. In this study, a distinction has been made between optional rule application, that is whether a rule does or does not apply and variable application, where a range of outcomes is observed.

The phonological rules taken together with the proposed model of phonetic implementation account for the observed facts from the data of English, including those which superficially appeared to be counter examples to the proposed model of implementation.

CHAPTER 6 CONCLUSIONS

In the preceding chapters, an in-depth study of the phonological and phonetic patterns of the feature Nasal in three languages – Sundanese, French and English – was carried out. This study was undertaken in order to investigate the relationship between phonology and phonetics, with particular attention to a segmental feature. Based on this investigation, a model of phonetic implementation has been proposed, whereby phonological feature specifications are mapped to targets which last for most of the duration of a segment. These are connected through interpolation, following two priority statements for transitions, as well as observation of certain phonetic constraints. In addition, syllable structure has the effect of limiting predicted long distance effects in French, and the proposed One Segment Principle limits long distance effects in English.

In §6.1, we compare our results across the three languages. In §6.2, we summarize the main ingredients of the proposed model. Finally, in §6.3, we consider implications of the proposed model and directions for further research.

6.1. Comparison of results across three languages





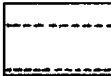
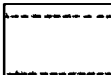

In the previous three chapters, we have looked in turn at nasalization in each of the three languages under investigation in this study. The treatments were not parallel, as in each case the most salient issues posed by the data were pursued. In this section, a brief comparison of the three languages is offered, in order to consider the issue of what is language specific and what is more general, perhaps universal, about implementation of the feature Nasal.

Systematically in all three languages, we observe that segments specified as [+nasal], either underlyingly or by phonological rule, are nasal for most or all of their duration without exception. The realization of "oral" segments is much more affected by context; we discuss the realization of vowels (§6.1.1), [+continuant] consonants (§6.1.2) and [-continuant] consonants (§6.1.3) in turn. In §6.1.4, we consider these results in light of the expected role of language specific phonetics.

6.1.1. Cross-linguistic patterns of nasalization of vowels

Vowels in the three languages are nasalized to differing degrees in different contexts. These patterns are argued to follow, for the most part, from phonological specification or lack thereof, as constrained by certain phonetic requirements. The assumed phonological representations and phonetic requirements for Sundanese, French, and English, appropriate for the speakers studies here, are summarized in (1).

(1) Comparison of the realization of the feature Nasal with respect to vowels

	Phonological Representation	Phonetic Requirements
Sundanese:	[+nasal] by Nasal Spread	
	[-nasal] by Default rule	
French:	[+nasal] } by UR or rule [-nasal] }	
		
	[Ønasal] / [+nasal] ____	
English:	[Ønasal]	
	[+nasal] by Nasal Deletion	

Sundanese appears to be the most constrained, as vowels are always specified as [+nasal] or [-nasal] leaving the phonology. With the exception of [a] / ____ [ŋ], where some cline-like nasalization was observed (a point that requires further investigation), all vowels were seen to be oral or nasal for most of their duration in a categorial manner. In the cases studied, since a phonological specification is always in effect, we do not have evidence for any particular phonetic constraints on the realization of vowels in Sundanese.

In French, most vowels are phonologically specified as [+nasal] or [-nasal], but we noted above that a non-nasal vowel in one particular context – after a [+nasal] specification – appears to be unspecified. In this one case, the phonetic constraints emerge, showing a range of possible values. Over the whole data set, the oral vowels are oral for most of their duration, with at most the final third affected by an upcoming [+nasal] segment, the nasal vowels are nasal for most of their duration, and a cline-like pattern is observed in the cases argued to be [Ønasal].

In English, no phonological specifications are in effect for vowels, except as a result of the rule of Nasal Deletion. Nasalization of vowels is very much determined by context, with increasing cline-like effects before a nasal consonant and decreasing cline-like effects following a nasal consonant. In these cases, a very weak phonetic constraint is in effect, imposing a ceiling on possible nasality on the vowels.

The pattern of anticipatory nasalization in English is quite different from that observed for French and Sundanese in that the effects are more pervasive (potentially affecting the full segment in a cline-like manner) and more variable. These differences are argued to follow directly from the fact that in English vowels leaving the phonology are unspecified for the feature Nasal, whereas those in both French and Sundanese are specified in this position (in Sundanese by a default fill-in rule, in French either underlyingly or by rule.)

We see that most of the differences in realization of vowels in these three languages are accounted for by differences in phonological representations, that is, specifications for the feature Nasal. Yet phonetic differences may play a role as well. The one context where such differences might emerge in the data analyzed is in the NV case in French and English. In this context in both languages, there are no phonological specifications, only phonetic constraints – phonetic windows – that determine the realization of nasalization. To facilitate a comparison of this context in French and English, three possible curves are schematized in (2).

(2)



The most common curve in both languages is a fairly straight cline through the segment, such as (2ii), predicted to result from straight interpolation through an unspecified span. Curve (2i) is also quite common in both languages. Yet there is an interesting difference: curve (2iii) is also quite common in English, but much rarer in French. In other words, high flow is not uncommon in English, but rare in French. Intuitively, these results seem appropriate, since French must maintain a contrast between NV and NV̄, while English does not. As a partial account, it seems quite likely that French has a narrower window than English for phonologically unspecified vowels. (More still needs to be said about possible interpolatory functions.) Further insight into the nature of the windows in French and English could be gained by comparing NV sequences with and without a following segment. Since a following frame was used in collection of all the data in this study, such a comparison is not possible with the present data set. Nevertheless, it appears that there is some difference in the phonetic constraints in French and English. This fits in with the conclusion that there are indeed language specific differences in phonetic implementation, as discussed in Chapter 1.

6.1.2. Cross-linguistic patterns of nasalization of [+continuant] consonants

In each of the three languages, [+continuant] consonants (and segments possibly unspecified for Continuant) were argued to be unspecified underlyingly for the feature Nasal. In both French and Sundanese, we saw that the phonetic effects of nasalization are quite local. This fact follows from the proposed representations. In Sundanese, this emerges from the fact that phonotactically there is never more than one phonologically unspecified segment in a sequence.

In the data for French, syllable structure was seen to play a role in limiting long distance effects. In the case of both /l/ and /j/, syllable structure was hypothesized to have an effect on the nasal specification of these segments. It was also tentatively suggested that syllable structure might account for slightly different patterns of nasalization in cases such as NVl\$ or NVj\$ and NVG\$ or NVjG\$.

In English, we have found little reason to assume that anything but [-continuant] segments are specified for Nasal leaving the phonology. English, with the least phonological constraints expected, was taken to be an optimal candidate for long distance effects, but such effects are much more limited than predicted. Vowels, glides and liquids are all greatly affected by a neighboring

nasal consonant, yet the effects are not generally long distance. The One Segment Principle was proposed to account for such observed limits on longer distance effects.

One wonders about the cross-linguistic status of the One Segment Principle proposed for English. If this interpolatory function is related to physiological tendencies of movement, then one might expect this function to be universal. The data from the speakers of Sundanese and French are basically compatible with this function, it is just that these effects are masked by phonological requirements. In Sundanese, no cases were observed with a sequence of two segments both phonologically unspecified for Nasal, since the long distance effects of nasalization are phonological, not phonetic. In French, the Syllable Onset Rule has the effect of preventing most longer sequences of unspecified segments, so here too, phonetic long distance effects are restricted by phonological specification. There is one exception to this: the case of a NVR sequence where the glide or liquid is in the rime with the vowel, in which slight effects over a second segment were observed. The status of this case and its implications for the One Segment Principle require further investigation.

Thus in each of the three languages, at least some [+continuant] consonants remain unspecified at the output of the phonology. In these cases, no phonetic constraints on the segments themselves were observed, but it might be that such segments are constrained by a very wide window, the limits of which we have not yet observed. Based on this limited sample of languages, it seems to be the case that phonetic effects of nasalization are bound by either the adjacent segment or a syllable boundary. But this does not rule out the possibility of languages where such limits are not observed.

In summary, we have observed that [+continuant] segments, or those unspecified for the feature Continuant, typically remain unspecified for the feature Nasal, a fact predicted by the proposed Configuration Constraint, whereby Nasal does not cooccur with $\begin{bmatrix} -\text{continuant} \\ +\text{consonantal} \end{bmatrix}$.

6.1.3. Cross-linguistic patterns of nasalization of [-continuant] consonants

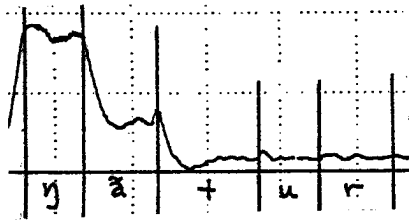
Before comparing the realization of [-continuant] consonants across the three languages, some attention needs to be given to the phonetic realization of these segments in Sundanese, a point that was not directly addressed in Chapter 3. The patterns in Sundanese are discussed in §6.1.3.1 and a comparison of the patterns in the three languages is presented in §6.1.3.2.

6.1.3.1. The phonetic realization of voiced and voiceless stops in Sundanese

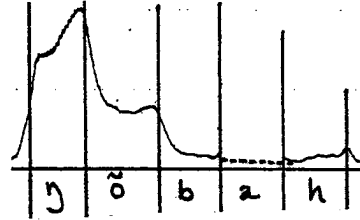
It was argued that both voiced and voiceless stops in Sundanese are phonologically specified as [-nasal], since there is a contrast within the class of [-continuant] for Nasal and because the oral stops function as blockers for the rule of Nasal Spread. Based on phonological specification, we expect both voiceless and voiced stops to receive oral targets for most of their duration. This is indeed the case for oral stops following a [+nasal] vowel, as shown in (3a and b); but in the case of an oral stop following a nasal consonant an interesting difference emerges, shown in (3c and d).

(3) Voiceless and voiced stops in Sundanese

a. /ɲatur/ 'arrange, active' [S-L 2]

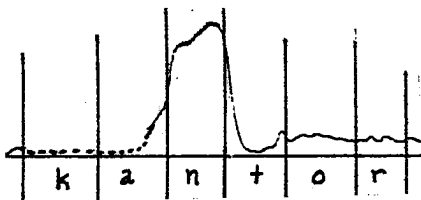


b. /ɲobah/ 'change, active' [S-L 4]

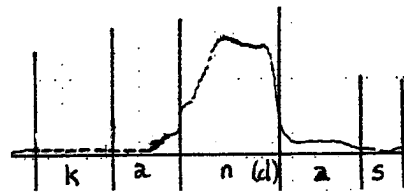


100ms

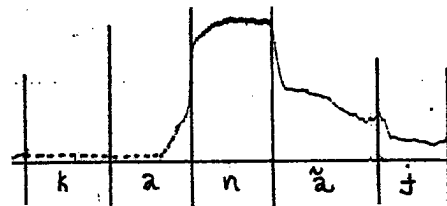
c. /kantor/ 'office' [S-L 3]



d. /kandas/ 'aground' [S-L 3]



e. /kana/ 'for the purpose of' [S-L 3]



In (3a) we see a voiceless stop following a nasal vowel. Here the transition from nasal to oral, during the beginning of the consonant, is a rapid one. The pattern with a voiced stop following a nasal vowel, shown in (3b), is very similar; again the transition occurs rapidly at the beginning of the stop. This is consistent with the view that the vowels and stops have [+nasal] specification and [-nasal] specifications respectively, mapped to nasal and oral targets respectively. As predicted by the proposed priority statements, it is the nasal vowel that dominates the transition.

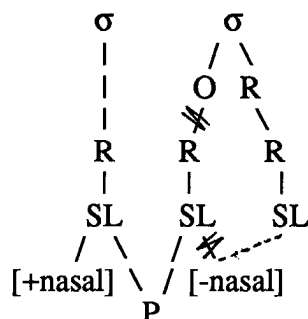
When a voiced or voiceless stop follows a nasal consonant, an interesting difference emerges. Here the pattern with a voiceless stop is parallel to the case following a nasal vowel, as seen in (3c), with the oral closure consisting of a clear nasal portion followed by a clear oral portion, each lasting approximately half of the duration. In contrast, in the case of a voiced stop following a nasal consonant, shown in (3d), significant nasal flow is observed throughout most of the duration of the oral closure. This is similar to the difference observed between voiced and voiceless stops in French in this position, where phonologically voiced stops were at least partially nasal, following a [+nasal] specification. Yet there are two significant differences. First, in French the pattern for voiced and voiceless stops is the same following either a nasal vowel or a consonant. Second, in the voiced stop case in French, there is a cline-like transition from nasal to oral throughout the latter half of the oral closure, consistent with the view that the voiced stop is unspecified for Nasal, whereas in Sundanese there is significant nasal flow, in a plateau-like

manner until the very end of the oral closure, similar to an NV pattern. This can be seen by comparing the NDV case (3d) with an NV case (3e). We see that the amplitude of flow is very similar in these two cases, with the main difference being the orality of the following vowel in the former case and the nasality of the following vowel in the latter case. Furthermore, this pattern occurs typically when the nasal-stop sequence is homorganic. Similar observations are made by Robins (1957):

Within a word, intervocalic sequences of nasal consonant followed immediately by a homorganic voiced plosive or affricate are frequently pronounced with a very light articulation of the non-nasal consonant. . . . In such cases the absence of nasality in the vowel following the plosive or affricate was found to be a more readily noticeable mark of the nasal + voiced consonant sequence as distinct from a single intervocalic nasal consonant. . . . (p. 91).

To account for the observed ND pattern, I propose a phonological rule of Homorganic Voiced Stop Deletion, where the [-nasal] specification is left floating and relinks to the right, to account for the absence of Nasal Spread, as presented in (4).





(4) Homorganic Voiced Stop Deletion (Sundanese)



A voiced oral stop is deleted following a homorganic nasal stop, leaving its [-nasal] specification floating, which relinks to a following vowel. I have represented the homorganic place specification as involving a shared place node. This predicts that this rule should not apply across word boundaries, where no shared place node would be expected. This fits with Robins' observations.

Homorganic Voiced Stop Deletion is another example of a stability effect for the feature Nasal. It also gives support to the conclusion that Nasal is not a monovalent feature, since it is another example where a [-nasal] specification is referred to by the phonology. Sample derivations are presented in (5) where /ŋobah/ and /kandas/ are compared.

(5) Sample derivations

Input:	a.	b.
	ɲ o b (a h)	(k a) n d a (s)
	R • • • 	• • •
	SL • • • 	• • •
	+N -N	+N -N
Nasal Spread:	ɲ o b	—
	R • • • 	
↙	SL • • • 	
+N	+N -N	
Homorganic Voiced Stop Deletion:	—	n d a • // • • • • ↘ +N -N
Default Fill-in:	—	—
Phonological Output:	ɲ o b / +N -N	n a +N -N
Phonetic Implementation:		
Target Assignment:		
Phonetic Constraints:	NA	NA
Priority Statements:	[+nasal] > [-nasal]	[-cont] > [+cont]
Interpolation:		

The inputs are as shown. In (5a), Nasal Spread applies, nasalizing the following vowel. Both Homorganic Voiced Stop Deletion and Default Fill-in are inapplicable, giving the phonological output as shown. In the phonetic implementation, the [+nasal] and [-nasal] specifications are mapped to nasal and oral targets respectively. No phonetic constraints are relevant, since the forms are fully specified phonologically. The [+nasal] specification has priority over [-nasal] in the transition, giving the phonetic pattern as shown. In (5b), Homorganic Voiced Stop Deletion applies, deleting the homorganic /d/, leaving the [-nasal] floating, which in turn

relinks to the following vowel (until then unspecified for the feature Nasal). The phonological output is as shown, with the specifications mapping to targets. Again, no phonetic constraints are applicable. In terms of the transition, [-continuant] > [+continuant], which, since the [-continuant] is also nasal, has the same effect as [+nasal] > [-nasal]. In point of fact, the transition does not seem to be fully dominated by the nasal consonant, a point that warrants further investigation.

In summary, we see that the proposed model, with the addition of the rule of Homorganic Voiced Stop Deletion in Sundanese, accounts for the Sundanese patterns exemplified in (3).

6.1.3.2. Patterns of nasalization of [-continuant] consonants compared

We are now in a position to compare the realization of voiced and voiceless stops in the three languages. Most generally, we observe that phonetically all oral stops have, at a minimum, an oral release, unless, as in the case of syllable final /t/ in English, there is glottalization, a point we return to in a moment. Phonologically, in most cases, both voiced and voiceless stops are assumed to be specified as [-nasal]. Thus, in these cases, both voiced and voiceless stops are mapped to oral targets for most of their duration in the phonetics. Yet in some cases, an interesting phonetic difference emerges, whereby a voiceless stop must be oral for most of its duration (presumably due to the phonetic requirements of being both [-continuant] and [-voice]), whereas a voiced stop may be oral only at its release.

It has been argued that phonologically specified voiced stops, like voiceless stops, have oral targets for most of their duration; thus a phonetic difference between the two is predicted to arise only if the voiced stop lacks a phonological specification of its own. Such differences are observed in the data from French, and are argued to result from the deletion of the phonological specification of a voiced segment following a [+nasal] specification, which in turn leads to interpolation through an unspecified span.

Yet the asymmetry in phonetic requirements on voiced and voiceless stops, which emerges clearly in the case of French, is more general. For example, partial nasalization of /d/ following a [+nasal] specification is observed by Huffman (1989) in Yoruba, and our own results for English are somewhat ambiguous on this point. A more systematic comparison of ND and NT clusters cross linguistically is warranted. The propensity for nasalization of voiced stops, and voiced segments more generally, following a nasal segment may well have to do with different perceptual thresholds for nasality following and preceding nasal segments.

One of the striking results of the present investigation is the possible nasalization of glottalized /t/ in English. Even though there is still an oral closure in these cases, nasalization appears to be possible, since no oral pressure build-up is required. This closely parallels the observed patterns of nasalization of glottal stop in Sundanese, where glottal stop is transparent to nasalization both phonologically and phonetically.

In conclusion, although several language specific phonological rules affect the realization of voiced and voiceless stops in the vicinity of nasal segments, the observed phonetic patterns are seen to be quite consistent across the three languages.

6.1.4. Role of language specific phonetics

In the present study, most of the observed differences in the data of the three languages under investigation have been attributed to the phonological specification or lack of specification of particular segments at the output of the phonology, with the processes of phonetic implementation quite constant across the three languages.

One of the basic premises we started with in Chapter 1 was that phonetic processes may be language specific and therefore part of the linguistic grammar. The general consistency of phonetic implementation across the three languages studied here does not argue against the importance of language specific phonetics. Cases cited in the literature independently establish the importance of language specific phonetics and the results of the present study are compatible with that conclusion. In this investigation, three languages with differing phonological uses of the feature Nasal were chosen, in order to be able to study the contribution of the phonology to phonetic implementation. Not surprisingly, such phonological differences are clearly reflected in the observed phonetic patterns and have perhaps overshadowed potential language specific phonetic differences. A fuller understanding of such language specific differences could be achieved by comparing the phonetic realization of languages which made a similar use phonologically of the feature Nasal.

Still the results of this investigation suggest a few areas where language specific phonetics might be expected to reside: (1) the specific nature of phonetic constraints, e.g. it was suggested that the window of possible values for vowels might be somewhat narrower in French than in English; (2) the role of priority statements, seen to hold in both French and English, but it was suggested that these might not be universal; (3) the pattern of feature specific interpolatory functions, e.g. the role of the One Segment Principle; (4) phonetic variability, expected to be in an inverse relationship with the degree of phonological specification (therefore tied in a general sense to the phonological patterning of a particular language). Further cross-language study will give insight into how language differences may be realized in the phonetics with respect to the feature Nasal.

6.2. Summary of the proposed model

In this section, we summarize the proposed model. In (6), the relevant aspects of rules and representations within the phonology are listed:

(6) The basic model: phonology

Underlying Representation:

- feature specified or unspecified

Phonology:

- phonological rules: feature spreading, deletion, relinking
- feature fill-in rules
- phonological constraints, e.g. configuration constraints

Output of the phonology:

- [+nasal], [-nasal], [Ønasal]

We have assumed that the underlying representation is unspecified for the feature Nasal, except to the degree required by phonological contrast. We assumed, most generally, that [-continuant] consonants are specified for the feature Nasal, since in each of the languages under investigation, there is an nasal-oral contrast for [-continuant] consonants, whereas [+continuant] consonants do not contrast in nasality.

The phonological representation can be acted on in several ways. There are different types of phonological rules that may manipulate the feature specifications, including the following: (1) feature spreading, as exemplified in Sundanese by the Nasal Spread rule, or in French by the Onset Assimilation Rule; (2) rules which involve deletion and relinking, such as Nasal Deletion in English and Homorganic Voiced Stop Deletion in Sundanese; and (3) feature fill-in rules, which may be general default specifications, such as the Default Vowel Fill-in rule in Sundanese, or determined by structure or context, such as the Syllable Onset Default Rule in French. Additionally, certain phonological constraints may be relevant, such as the proposed Configuration Constraint that Nasal cannot cooccur with $\left[\begin{smallmatrix} +\text{continuant} \\ +\text{consonantal} \end{smallmatrix} \right]$. This was argued to account for the fact that in Sundanese [+continuant] consonants are unspecified for the feature Nasal, yet function as phonological blockers. It is also consistent with the lack of phonological specification for these segments in both French and English as well, except as specified by syllable position in French.

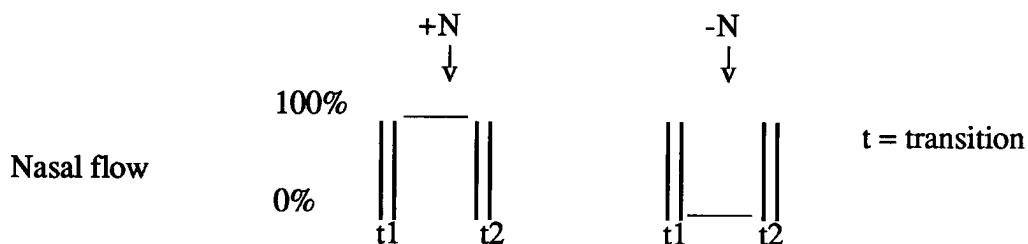
We conclude that there is not necessarily full specification at the output of the phonology, a view supported by the data of all three languages. Thus for the feature Nasal, each segment is either specified as [+nasal], [-nasal], or remains unspecified.

It is the representation at the output of the phonology which the phonetics manipulates in the ways summarized in (7):

(7) The basic model: phonetics

Target assignment:

- mapping from feature specifications to targets, which consist of full durations with transitions.



Phonetic constraints:

e.g. voiceless stops



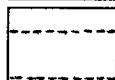
oral for full duration

voiced stops



oral at release

vowels



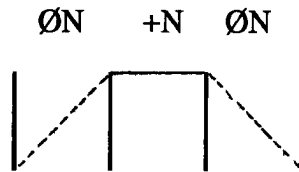
range of values

Priority statements:

- [-cont] > [+cont] iff [-cont] / ___ [+cont], [+nasal] > [-nasal] elsewhere.

Interpolation:

- interpolation between targets, following priorities and phonetic constraints.
- including a velum specific interpolatory function, observed in English, the One Segment Principle, whereby the velum, given no contradictory information, takes about one segment's duration for a transition.



Each phonological specification at the output of the phonology is mapped to a target for most of its duration, except for the edges, or transitions. Only segments with a phonological specification receive a target. The phonetics introduces phonetic constraints on segment well-formedness, which are relevant when a segment is phonologically unspecified, since if it has a phonological specification, this will potentially mask the phonetic requirement. Priority statements are responsible for dominance over transitions (integrating the notion of transition developed by Holmes, Mattingly, and Shearme 1964). Interpolation then takes place between targets, following relevant priority statements and phonetic constraints. Interpolation is observed to be fairly linear, within the additional constraint imposed (at least for English) by the One Segment Principle.

This model accounts for the overall patterns of nasal airflow observed in a wide range of contexts in the three languages under investigation, although many finer details of the phonetic flow patterns have been left aside.

6.3. Conclusions and directions for further research

One of the central goals of this study was a characterization of the mapping from an abstract categorial representation to a phonetic one, realized in time and space. We took at a starting point a target-interpolation model, such as that developed in the study of intonation by Pierrehumbert (1980). In our investigation we have found strong support for the general approach of a target-interpolation model.

Within a target-interpolation model, we have assumed that there is not necessarily full specification leaving the phonology; in other words that underspecification may play a role in the phonetics (following Pierrehumbert 1980, Keating 1985a, 1988b). In addition, we have assumed that categorial vs. gradient phonetic outputs, when judiciously interpreted, can be used as a heuristic for identifying phonological vs. phonetic processes (Keating 1987, 1988a).

We found independent evidence for both of these assumptions. First, it was argued that the blocking effects of [+continuant] consonants on Nasal Spread in Sundanese must be due to a Configuration Constraint, rather than to redundant nasal specifications. The [+continuant]

consonants must necessarily be unspecified for Nasal at the output of the phonology in order to account for the observed phonological opacity of these segments vs. their phonetic transparency. Second, we found independent evidence from cyclicity and rule ordering to support a distinction between phonological and phonetic processes, which correlated as predicted with categorial and gradient results. This result was most striking in the case of Sundanese, where Nasal Spread, a phonological rule, had categorial results, whereas interpolation through an unspecified span, a phonetic process, yielded gradient results, as discussed in Chapter 3. It is the hypothesis that feature specifications map to targets with inherent duration (a point we return to in a moment) that underlies the type of heuristic proposed by Keating. These results support the view that much insight into the phonological structure can be gained through a systematic study of phonetic data (a view central to the work of both Pierrehumbert and Keating).

A target-interpolation model was argued to account for the observed patterns of nasalization in the data in each of the three languages, with extensions in two directions. (1) Targets cannot be timeless points, but necessarily have inherent duration (implicit in Keating 1988a and also argued by Huffman 1989 and Pierrehumbert and Beckman 1988). More specifically, targets for nasality have an inherent duration of most of the duration of a segment, with priority statements to determine which segment dominates the transition in any particular case. (2) The phonetics may impose its own constraints, either with respect to acceptable values for a particular segment class (an extension of Keating's 1988a window model) or with respect to the nature of interpolation for a particular feature (or articulator).

The feature Nasal was chosen as a case study in order to compare the implementation of a segmental feature (albeit one that can behave quite independently) with the better studied implementation of intonation. Most generally, we have observed that the basic patterns of implementation of Nasal are quite similar to those observed for intonation. However, because there are many more specifications in closer proximity, the nature of targets and their placement become more central issues. The incorporation of inherent duration in targets is motivated on both empirical and theoretical grounds. In the data in each of the three languages, phonological specifications, both [+nasal] and [-nasal], are seen to result in a plateau-like pattern of either presence or absence of flow for most of the duration of the segment. Intuitively, if a particular feature specification is in essence "stretched out" when it is realized in time and space. This conclusion also fits in with the more phonetic arguments of phonetic implementation put forth by Huffman (1989), where inherent durations of targets (at least for some classes of segments) are motivated by the important role of closure and release, i.e. the edges of segments.

An explicit proposal about the realization of phonetic requirements of segments – their phonetic well-formedness – was made: independent from phonological specification, the phonetics might impose certain constraints. These phonetic requirements are, in many cases, masked by the phonological specifications and only emerge when segments are unspecified leaving the phonology. This overlapping relationship between phonological specification and phonetic requirements captures the fact that at times the relationship between phonology and phonetic is quite a natural, direct one, but at times it is not (see Anderson 1981). It was also argued that there may be articulatory-specific interpolatory functions, such as the One Segment Principle proposed to account for observed limits on longer distance effects of nasalization in English.

Other types of phonetic constraint may come into play as well. It was seen that syllable structure played a phonological role in French, in determining appropriate feature specifications,

but it also appears to be the case that syllable structure might play a phonetic role in accounting for some of the smaller details of segment durations, local turning point of onsets and offsets of nasalization, and so forth. The role of syllable structure at this level is clearly demonstrated by Krakow (1989) in her study of coordination of labial and nasal gestures in English.

This investigation has answered some questions about the nature of the mapping from phonology to phonetics, but has inevitably raised many more, including the following.

There is much still to be investigated about the feature Nasal. Although an extensive corpus of data was presented for the three languages under investigation, there are numerous additional cases for these three languages that merit further study. In addition, the results obtained here must be taken as somewhat tentative without data from many more speakers of each of the three languages. As noted in §6.1.4, in the present study three languages with quite different phonological uses of the feature Nasal were investigated; such investigation should now be extended to additional languages with similar phonological patterns for the feature Nasal, in order to better understand the role of language specific phonetics.

Another obvious direction for further research is the applicability of the proposed model to other features. It is predicted that certain aspects of the model, e.g. phonological specifications mapping to targets with inherent duration, should play a central role in the implementation of other features, but other aspects of the model may be feature-specific.

There are other aspects of phonetic implementation that were not the focus of the present investigation that need to be better understood before a complete model of phonetic implementation will emerge. These include, most notably, an adequate model of phonetic timing (and an understanding of its relationship to phonological timing), a better understanding of the role of variability in phonetics, investigation of the perceptual relevance of the phonetic patterns observed here, and attention to finer details of implementation. Only when all of these aspects of phonetic implementation are fully understood will an explanatory theory of implementation emerge.

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APPENDIX A SUNDANESE WORD LIST

The frame sentence was /tulis _____ jəlas/ 'say _____ clearly'.

A fairly large inventory of segments was used in order to allow the construction of appropriate contexts for Nasal Spread.

∇ = nasalized vowel due to Nasal Spread

R = form cited by Robins (1957)

√ = kymographic tracing presented by Robins (1957)

A. Oral and nasal controls, to compare flow levels for different vowel qualities

<u>transcription</u>	<u>Sundanese ortho</u>	<u>gloss</u>	<u>pattern</u>	<u>R</u>
atur	atur	arrange	VCVC	
ɳatur	ngatur	arrange, act.	NVCVC	
isər	iser	move or displace	VCVC	
ɳisər	ngiser	move, act.	NVCVC	
obah	obah	change	VCVC	
ɳobah	ngobah	change, act.	NVCVC	
udag	udag	pursue	VCVC	
ɳudag	ngudag	pursue, act.	NVCVC	

B. VV, VhV, and V∇V sequences

NVV and controls

siar	siar	seek	VV	
ɳiar	nyiar	seek, act.	NVV	√
dicaian	dicaian	wet, passive	VV(n)	
ɳaian	nyaian	wet, act.	NVVVN	√
saur	saur	say	VV	
ɳaur	nyaur	say, act.	NVV	R

N=ar=VV

ɳ=ar=aian	nyaraian	seek, act., pl.	N=ar=VVVN	R
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N=al=VV

ɳ=al=iar	nyaliar	seek, act., pl.	N=al=VV	
ɳ=al=aur	nyalaur	say, act., pl.	N=al=VV	√

NV∇V and controls

tiis	tiis	relax in a cool place	V∇V	
niis	niis	relax, act.	NV∇V	√
piasih	piasih	love	VV	
miasih	miasih	love, act.	NV∇V	√
saat	saat	dry	V∇V	
ɳaatkin	nyaatkeun	dry, act.	NV∇V	
tuus	tuus	dry	V∇V	
nuus	nuus	dry, act.	NV∇V	

N=ar=V∇V

n=ar=iis	nariis	relax, act., pl.	N=ar=V∇V	√
m=ar=iasih	mariasih	love, act., pl.	N=ar=VV	

n=ar=aatkin	nyaraatkeun	dry, act., pl.	N=ar=VɤV
n=ar=uus	naruus	dry, act., pl.	N=ar=VɤV

NalVɤV
not exemplified in the corpus

NVhV and controls

pihak	pihak	sides	VhV	
mihak	mihak	take sides, act.	NVhV	
dahar	dahar	eat	VhV	
mahal	mahal	expensive	NVhV	R
ꦤꦲ	nyaho	know, act.	NVhV	R
ꦏꦤꦲꦲꦺꦴꦤ	kanyahoan	to become known	NVhV+V	
tuhur	tuhur	dry	VhV	
nuhurkin	nuhurkeun	dry, act.	NVhV	

N=ar=VhV

m=ar=ihak	marihak	take sides, act. pl.	N=ar=VhV	
m=ar=ahal	marahal	expensive, pl.	N=ar=VhV	√
n=ar=aho	nyaraho	know, act. pl.	N=ar=VhV	R

N=al=VhV

n=al=uhurkin	naluhurkeun	dry, act. pl.	N=al=VhV	
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C. VrV, VIV, non-infixed forms to be compared with near minimal pairs with infixes

parios	parios	examine	VrVV	
marios	marios	examine, act.	NVrVV	√
ꦤꦫꦲꦲꦺꦴꦤ	ngaraheutan	wound, act.	NVIVhV	
kuliat	kuliat	stretch	VIVV	
ꦤꦭꦶꦠ	nguliat	stretch, act.	NVIVV	√
luhur	luhur	high	IVhV	
ꦤꦭꦸꦲꦸꦫꦤ	ngaluhuran	be in a high position, act.	NVIVhV	

D. VGV (underlying) sequences to be compared with near minimal pairs with VV

ꦤꦶꦮ	ngiwat	elope	NVGV
awur	awur	spread	VGV
mawur	mawur	spread, act.	NVGV
kawih	kawih	sing	VGV
ꦤꦶꦮ	ngawih	sing, act.	NVGV
ajak	ajak	sift	VGV
ꦤꦶꦗ	ngajak	sift, act.	NVGV

E. Additional forms with [h]

ꦧꦶꦁꦲ	beunghar	be rich	.Nh.	√
imah	imah	house	VNVh	
imah-imah	imah-imah	set up house	VNVh-VNVh	

F. N vs. Nd vs. Nt sequences

kadal	kadal	ground lizard	CVCV
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kana	kana	for the purpose	CVN∇
kandas	kandas	aground, ashore	CVNDV
kantor	kantor	office	CVNTV
sisir	sisir	comb	CVCV
sinar	sinar	ray of light	CVN∇
sindir	sindir	sneer	CVNDV
sintir	sintir	twirl a coin	CVNTV

G. NI / Nr and IN / rN sequences, recorded for S-L only

anjrem	angrem	ripen	VNrVN
cajra	cangra	very nice weather	VNrV
paŋlai	panglai	a type of plant	VNIV
paŋliŋ	pangling	unrecognizable	VNIVN
almari	almari	cupboard	VIN...
delman	delman	carriage	VIN
warna	warna	color	VrN
hormat	hormat	respect	VrN

APPENDIX B FRENCH WORD LIST

The frame sentence was *dites* __ *deux fois* [dit dø fwa] 'say _____ twice'. The symbol % is used to indicate that a particular form appears more than once on the list.

The inventory of segments used in the French data is as follows. Where possible coronal consonants were used and except for /t/ only voiced segments were studied.

voiced stops:	d, b
voiceless stops:	t
liquids:	l
glides:	j
oral vowels:	ɔ, o, ε, e
nasals:	n, (m)
nasal vowels:	ɛ̃, ɔ̃ (ã)

A. -N -N

These cases were used as controls.

<u>transcription</u>	<u>orthography</u>	<u>gloss</u>	<u>pattern</u>
bo	beau	handsome	DV
bot	botte	boot	DVT
dɛ	dais	canopy	DV
dɛ	dé	dice	DV
dɛt	dette	debt	DVT
do	dos	back	DV
dɔt	dot	dowry	DVT
lɛ	lait	milk	IV
tjed	tiède	warm	TGVD
to	tôt	soon	TV
vɛ	vais	go 1s	vV

B. -N+N CN, C∇, (C)VN, V∇

CN			
ditnV	dites n. . .	say . . .	t#n
ledmã	laidement	in an ugly way	dm
bɛlnɛl	belle Nel	pretty Nell	l#n
C∇			
bɔ̃	bon	good	D∇
dɛ̃	daim	deer	D∇
dɔ̃	don	gift	D∇
tɔ̃	thon	tuna	T∇
lɛ̃	lin	flax, linen	I∇
lɔ̃	long	long	I∇
vɛ̃	vin	wine	v∇
ljɔ̃	lion	lion	IG∇

tjɛ	tien	yours	TGV
vjɛ	vient	come (3s.)	vGV

(C)VN

bɔn	bonne	good	DVN
dɛn	daine	doe	DVN
dɔn	donne	card deal	DVN
tɔn	tonne	ton	TVN
lɛn	laine	wool	IVN
vɛn	veine	vein	vVN
ljɔn	lionne	lioness	IGVN
tjɛn	tienne	yours	TGVN
vjɛn	viennent	come (3pl.)	vGVN

also compare

bɔ ne	beau nez	pretty nose	DV#NV	%
bɔne	bonnet	cap	DVNV	%
tɔne	tonner	to thunder	TVNV	%
bɔn\$os	bonne hausse	good rise	N#V h aspiré	%
bɔnɔs	bon os	good bone	N#V liaison	%
bɔnɔd	bonne ode	good ode	N#V enchain- ment	%

VV

leɜ	Léon	Leon	IVV	
ileɛero	il est un héros	He is a hero.	VVV	%

C. +N-N

NC, VC, NV(C), VV

NC

ndø	... n deux	... n two	n#d
nje	nier	to deny	NGV
nje	niais	simple	NGV F-D only
bɔndɛt	bonne dette	good debt	nd
bɔntɛt	bonne tête	good head	nt
bɔnletɾ	bonne lettre	good lettre	nl

VC

.. ʃ#d	.. on d	.. on two	V#C
.. ɛ#d	.. ain d	.. ain two	V#C
bɔle	bon lait	good milk	VIV
bɔte	bonté	goodness	VtV
dɛd	dinde	turkey, f.	V#C
bɔb	bombe	bomb	V#C
tɔt	tonte	sheep shearing	V#C

NV(C)

ne	nez	nose	NV
----	-----	------	----

net	net	clean	NVT	
not	note	note	NVT	
bɔncɔd	bonne ode	good ode	N#V enchain- ment	%
bɔncɔs	bon os	good bone	N#V liaison	%
mele	mêler	to mix	NV\$IV	
maj	maille	stitch	NVG\$	
majo	maillot	(swim)suit	NV\$GV	
bɛlnɛl	belle Nel	pretty Nel	NVI\$	%

∇V

bɔ̃ero	bon héros	good hero	C∇V	
ilɛ̃ero	il est un héros	he is a hero	V∇V	
ilvɔ̃ao	ils vont en haut	they are going upstairs	V∇V	%

D. N∇, ∇N, ∇∇, NN

N∇

nɛ	nain	dwarf	N∇	
nɔ̃	non	no	N∇	
lãdmɛ	lendemain	next day	∇dN	%
lãtmã	lentement	slowly	VtN	%

∇N

bɔ̃ ne	bon nez	good nose	D∇#NV	
tɔ̃ ne	ton nez	your nose	T∇#NV	
as controls				
bo ne	beau nez	pretty nose	DV#NV	%
bone	bonnet	cap	DVNV	%
tɔ̃ ne	tonner	to thunder	TVNV	%

∇∇

bɔ̃ɔ̃grwa	bon hongrois	good Hungarian	∇∇	
ilvɔ̃ao	ils vont en haut	they are going upstairs	∇∇V	%

NN

bɔ̃nɔt	bonne note	good note	VNNV	
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E. +N -N +N sequences

+NC+N (both N and ∇)

Of the four logically possible cases, ∇C∇, NC∇, ∇CN, *NCN, the last does not occur and the second is rare, except if it involves a glide as the C.

VCV

bɔ̃ɔ̃	bon thon	good tuna	ViV
lwɛtɛ	lointain	distant	ViV
dɛdɔ̃	dindon	turkey, m.	VdV
bɔ̃lɛ	bon lin	good flax	ViV
bɔ̃jaki	bon yankee	good Yankee	VjV

VCN

lɑ̃dmɛ	lendemain	next day	VdN
lɑ̃tmɑ̃	lentement	slowly	ViN

NCV

ynjɔ̃	union	union	NjV
mje	mien	mine, m.	NjV

+N V +N

There are four logically possible cases: NVN, NVV, VVN, VVV. Of particular interest is a comparison of NVN and N̄VN.

NVN

nɛn	naine	dwarf	NVN
nɔ̃n	nonne	nun	NVN

NVN vs. N̄VN

mɔ̃nɛ	monnaie	money	NVNV
nɔ̃nɛt	nonnette	young nun	NVNV
mɔ̃nɛ	mon nez	my nose	N̄VN
nɔ̃nɛl	non-nul	non-null	N̄VN F-F only
nɔ̃nɛtrɛ	non-être	non-entity	N̄VN

F. VVN & NVV

boem	Bohême	Bohemia	CVVN
leɔ̃nɔ̃r	Léonore	Leonora	CVVN
lineɛr	linéaire	linear	NVV
nɔ̃ɛl	Noël	Noel	NVVI
nɛɔ̃ɛbrɛdɛ	néo-hébridais	of the New Hebrides	NVVV

V̄jVN & NjVN

bɔ̃jen	bon yen	good yen	V̄jVN
mjen	mienne	mine, f.	NjVN

APPENDIX C ENGLISH WORD LIST

The frame sentence was *repeat _____ twice* [rəpɪt _____ twaɪs]. This was changed to *repeat _____ Kate* for the third through fifth repetitions for Speaker E-F.

The following inventory of segments was in the corpus of English data:

voiced stops:	b, d
voiceless stops:	p, t, (k)
nasals:	n, (m)
liquids:	l, r
glides:	j
vowels:	i, ε

A. -N-N

These cases were used as controls.

<u>transcription</u>	<u>orthography</u>	<u>pattern</u>
ped	ped	TVD
pet	pet	TVT
det	debt	DVT
dɛd	dead	DVD
dɪd	deed	DVD
bɪt	beat	DVT

B. -N+N (C)VN, CN

(C)VN

bin	bean	DVN
dɪn	dean	DVN
lɪn	lean	IVN
rɛn	wren	rVN
jɛn	yen	jVN
lɛn	Len	IVN
pɛn	pen	TVN
dɛn	den	DVN

CN

rɛdɲɛk	redneck	D\$N
bɪtɲɪk	beatnik	T\$N
ɛlm	elm	IN
kɔɹn	corn	rN
dɑɪn	dine	jN

VVN - The following forms create possible environments for longer distance anticipatory effects.

rɛɪn	rain	VjN
rɛɪən	rayon	VVN

bàjénił	biennial	VGVN
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C. +N-N NV(C), NC(V)

NV(C)

net	net	NVT
nəd	Ned	NVD
nəl	Nell	NVI
ni	knee	NV
nit	neat	NVT
nid	need	NVD
nił	kneel	NVI
nir	near	NVr
nałt	night	NVj(T)

NVV - These cases may show longer distance carryover effects.

naıfv	naive	NVjV
nıo	neo	NVV
bàjénił	biennial	VGVN

NC

sent	sent	VNT
send	send	VND
séntə	center	VNTV
séntàr	centaur	VNTV
sénda	sender	VNDV
pend	penned	VND
pent	pent	VNT
péni	penny	VNV
əpéndə	appender	VNDV
rəpéntə	repenter	VNTV
pénlérə	pen letter	VNIV
kénił	kennel	VNI
hénri	Henry	VNrV
tənə	tenor	VNr

D. +N+N

NN		
čimni	chimney	NN
dæmnéıfı	damnation	NN
fáıfınes	fineness	NN

E. +N-N+N

NVN		
men	men	NVN
min	mean	NVN
nan	none	NVN

NCN		
káɲdnès	kindness	nd + n
fɛɲntnès	faintness	nt + n

F. Syllable structure

VNV (ambisyllabic), V\$NV

bì\$nit	Be neat	DV\$NV
bíni	beanie	DVNV
élmə	Elmer	INV
tèl\$moɾ	Tell more.	I\$NV

NVC(V) vs. NV\$C

nídi	needy	NVDV
nìdíp	knee deep	NV\$DV
itsmíl	It's meal.	NVI
itsmíli	It's mealy	NVIV
itsmí\$li	It's me, Lee.	NV\$IV
míni	meany	NVNV
mì\$niðə	me neither	NV\$NV. . .