Postlexical Palatalization in English: An Acoustic-Phonetic Study

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POSTLEXICAL PALATALIZATION IN ENGLISH:
AN ACOUSTIC-PHONETIC STUDY

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ABSTRACT

In Lexical Phonology, the nature of postlexical rules in English is controversial. A rule is considered discontinuous when applied lexically, but continuous when postlexical. There are also claims in the literature that postlexical rule application comprises a temporal component.

I performed three acoustic-phonetic experiments to examine the fine acoustic detail of a common English sandhi rule: inter-word palatalization. I examined both palatalization of stops, as in e.g. "did you", and fricatives, as in e.g. "gas shortage".

The results of my experiments show that English postlexical palatalization is both discontinuous and continuous. It is discontinuous in that it is a feature-changing rule. It is also continuous in that the palatalized allophones differ temporally from their non-palatalized counterparts.

Durational patterns of palatalized sequences are not like anything found in word-initial or word-final segments. As the durations of stops and fricatives that have been palatalized are not the same as durations of the segments specified in the lexicon, they therefore must be
postlexical.

In Experiment 1 I compared mean second formant endpoints at palatalization sites with those into alveolar stops and into palato-alveolar affricates. Transitions into palatalized sequences did not differ substantially from those into palato-alveolar affricates. This provides acoustic evidence for a discontinuous feature-changing rule.

In Experiment 2 I compared durations of palatalized stop + glide sequences with those of affricate allophones in word-initial, -medial and -final positions, as well as inter-word stop + fricative clusters. Affricates showed durational allophonic variation at word boundaries, and the durations of palatalized sequences differed from word-initial affricate allophones.

Experiment 3 examined palatalization of fricatives by fricatives, glides and affricates. I compared mean second formant endpoints preceding palatalized sequences with those preceding palato-alveolar and alveolar fricatives, and found acoustic evidence supporting the phonological description of palatalization as a discontinuous, feature-changing rule.

However, durations of palatalized fricatives were shorter than those of inter-word geminates. This indicated that length of the palatalized allophone is an integral component of its specification.

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POSTLEXICAL PALATALIZATION IN ENGLISH: AN ACOUSTIC-PHONETIC STUDY

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Margot Tamara Peet
to Dick
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Chapter 1

Introduction

The nature and source of variability in connected speech are among the most intriguing of the speech signal's uncharted mysteries. It is well known that variability arises from both linguistic and paralinguistic sources: in this dissertation I will examine some linguistic sources of variability arising from word juncture and show how experimental studies of the speech signal's fine detail shed light on phonological controversies concerning the nature of sandhi processes.

It is surprising to note that although there is a sizable phonetic literature examining phonological concepts such as acoustic correlates of features (e.g. Ohala, 1985), experimental phonetic studies of phonological rules are regretably few (for notable exceptions, see Dinnsen, 1985 and studies mentioned therein; also Liberman and Pierrehumbert, 1984). Similarly, the phonological literature reveals only minimal interest in the relevance of experimental phonetics to rule representation (for an exception, see Devine and Stephens' (1980) well-intended but limited attempt).

The study of external sandhi rules presents an even more disjointed picture. The phonetic literature contains a substantial amount of research on junctural processes in English, e.g. Lehishe, 1960, Klatt 1976, to name a few,
much of it stemming from practical considerations in speech synthesis and, more recently, machine recognition of speech. Yet this body of literature lacks a coherent theoretical framework in which to place individual studies.

On the other hand, it would probably not be too strong a statement to say that external sandhi rules are the stepchild of phonology, having in the past been relegated to various phonetic (Trubetzkoy, 1969) and morphophonemic (Hooper, 1976) levels.

Yet these inter-word processes are important for the phonologist because their domain is an interface between phonology and phonetics. Experimental studies are of particular relevance. As Dinnsen (1985) notes (p. 271), there are a number of interesting questions about the character of phonological rules and the presumed relationship between perception and production. One question is whether phonological rules describe production or perception phenomena. Although generative theories of phonology (Chomsky and Halle, 1968) presume an abstract grammar neutral with respect to speaker and hearer, Dinnsen points out that phonological descriptions of rule-governed allophonic phenomena must of necessity be production oriented, as these different phonetic realizations of the same phoneme are presumed to describe production differences not generally self-discriminable by native listeners.

Finally, a better understanding of inter-word rules
gives the speech researcher information on the principles and manifestation of word parsing strategies in the speech signal, and is thus crucial to the problem of lexical access.

One of the less fortunate results of interdisciplinary approaches to the phonetic representation of junctural rules is a lack of standard terminology. For this reason, in the following I will review some of the primary concepts to be examined, and will define their use in this dissertation, as well as review certain issues relevant to their formulation.

1.1 Terminology

1.1.a. Word

Basic to any discussion of juncture is what is meant by a word. What, exactly, a word is is the source of intense interest in morphological and phonological research (e.g. Simpson and Withgott, 1986). A word, in this dissertation, is considered to be a phonological word. Matthews (1974) describes a phonological word, as opposed to a grammatical word, as a unit in the hierarchy at that level, i.e., the phonological level. It is established ultimately by phonological, rather than grammatical, criteria (p. 32).

1.1.b. Connected Speech

It is also important to define what is meant in this
dissertation by connected speech. The "connected speech" studied in my experiment on inter-word palatalization is read sentences. Traditionally, much of phonetic research has been based on "laboratory" speech consisting of test words embedded in carrier sentences. From a phonetic standpoint, however, there is evidence that extrapolation from one speech form to another may not be justifiable.

Opinions vary considerably on the reliability of applying conclusions based on one kind of speech to another. Klatt (1976) compared durational data from nonsense syllables (Oller 1973), read discourse (Klatt 1975, Umeda 1975) and spontaneous speech (Kloker 1975) and found more similarities than differences. On the other hand, drawing from a collected database of read speech, Crystal and House (1982) observed numerous discrepancies between phonetic observations based on laboratory speech and those observed in connected, read discourse. In another study comparing spontaneous speech to read speech, Bernstein and Baldwin (1985) found the two to differ considerably.

Phonologists operate under similar presuppositions. Phonological judgements of inter-word processes are based on idealized utterances. There are, unfortunately, few studies of allegro variants (for a notable exception, see Zwicky, 1972).

Clearly, both phonologist and phonetician use somewhat
idealized forms as models, much as the syntactician does. What is questionable is how valid a model it is. The type of connected speech examined in this dissertation is defined as sentences read in a relaxed, conversational manner.

1.1.c. Inter-word Processes

Borrowing from the Sanskrit tradition, inter-word phonological or morphological processes are often referred to as sandhi, < Skt. samdhi "joining" or "putting together" (Bloomfield, 1933, p. 186, fn. 1). Also borrowing from the Sanskrit grammarians, sandhi processes at word boundaries are generally referred to as "external sandhi" (Matthews, 1974).

American structuralists favored the term juncture. This terminology was also employed in the phonetics literature of the 1950's and 1960's, most notably Lehiste (1960) who refers to internal open juncture.

In current usage, sandhi is a broad cover term for a variety of divergent phenomena occurring at word boundaries. Dissatisfied with this state of affairs, Ternes (1986) proposed an arrangement of sandhi phenomena with respect to their position within the grammatical hierarchy. On the lowest level is allophonic variation, specifically such phonetically non-transparent allophones as English word-final dark /l/. On the next highest level comes phonotactic restrictions, and then "internal sandhi"
or allomorphic variation. Finally come the phonetically motivated phonetic or phonemic alternations occurring at word boundaries for which, he argues, the term "sandhi" should be reserved. It is these phenomena that I will refer to as sandhi in this dissertation.

Lexical Phonology (e.g. Kiparsky, 1985) refers to processes occurring after the lexical cycle as postlexical (for further discussion, see Chapter 2). In this dissertation I will use the terms "inter-word processes", "juncture" and "external sandhi" interchangeably. "Postlexical processes" will be reserved for specific reference to the Lexical Phonology framework.

1.1.d. Coarticulation and Assimilation

1.1.d.1. Coarticulation

Coarticulation is often relegated to the status of a low-level phenomenon, operating without regard to higher-level considerations. Yet experimental studies of these phenomena have turned up evidence of the incorporation of some of these phonetic effects into the phonology of various languages, e.g. Keating's comparison of /h/ and /x/ coarticulation in English and Polish, which indicate that in Polish, intervocalic velar fricatives preceding a high front vowel are fronted throughout the consonant's duration, whereas in English, intervocalic /h/ connects the vowels rather than adopting the properties of the following vowel (personal communication).
Although few would argue that many phonological assimilation rules are not instances of phonologized coarticulation, attempts in the literature to integrate experimental investigations of coarticulation with phonological theory explaining assimilation rules are rare. The studies that have utilized this "hybrid approach", as it is referred to in Liberman & Pierrehumbert, (1984), have been thought-provoking and insightful. It is this experimental approach to a phonological rule that will be taken in this dissertation, in the hope that it will contribute to an integrated theory of speech and language.

1.1.d.2. Assimilation and Models of Coarticulation

Models of coarticulation and, more specifically, of assimilation, are relevant to a better understanding of assimilatory rules.

In an attempt to understand the nature of coarticulation, the "articulatory interactions among segments, and the acoustic consequences of these interactions" (Keating, 1985, p.1), numerous models have been posited, among them Henke (1966), Öhman (1966,1967), and Daniloff and Hammarberg (1973), to name a few.

Keating (1985) succinctly describes two models of coarticulation as they might relate to phonological consideration: (1) an articulation associated with one segment but not with its adjacent neighbor extending over from that first segment to the second; or (2) an
interpolation between adjacent segment values for a single articulator so that the entire time span in between shows their influence. In either model, segmental boundaries are blurred, calling to mind Hockett's Easter egg analogy (1955) which likens coarticulation to the indeterminate blurred mass of color resulting from Easter eggs being crushed.

Assimilation can be considered a form of coarticulation, in which the phonetic value of a segment is adjusted according to its context. Keating's (1985) description is particularly relevant to this discussion. She calls it a spatial effect rather than a temporal one, because the spatial target for a segment changes. The crucial difference is that spatial assimilation affects the entire segment's target, while coarticulatory overlap does not. She admits, however, that it is no simple matter to determine whether any given instance of coarticulation is primarily temporal overlap or spatial assimilation.

1.1.e. Palatalization

In a cross-language study of palatalization, Bhat (1974) notes that defining palatalization is a difficult task, as the use of the term in linguistics is varied. Although generally referring to assimilation of a consonant by a neighboring front vowel or palatal semivowel, it less frequently refers to assimilation of a consonant to a neighboring palatal consonant, unconditioned palatalization.
and also some changes resulting from rapid speech, or symbolizing diminutive formation (p.19).

He declines to offer a concrete definition, but notes that it is possible to specify two different conditions in such a way that the presence of at least one of them would automatically bring a change that would be considered palatalization. They are: (a) the conditioning environment must be a palatalizing one, i.e. it must be a front vowel, a palatal semivowel, or a palatal or palatalized segment; and (b) the sound resulting from the change must be palatal or have a secondary palatal articulation.

The phonological literature describing palatalization in English typically describes it as an assimilation rule:

\[ [+\text{alv}] \rightarrow [+ \text{pal}] \]

(Halle and Mohanan, 1985)

Although other places of articulation such as velars and labials, can be palatalized, palatalization referred to in this dissertation is solely palatalization of alveolar obstruents.

Palatalization as a word-internal process has received considerable attention in the phonological literature (e.g. Chomsky and Halle, 1968, Rubach, 1981), but palatalization as a word-external process has not. It has either tacitly been assumed that the word-external process is identical to the word-internal one, or, as is more likely, is a result
of lack of interest in phonological inter-word processes.

1.1.f. Phonological and Phonetic Rules

A basic definition of a phonological rule adopted in the literature is one which alters a segment's distinctive feature. The change is considered a categorial one (Keating, personal communication), in which the segment moves from one category to another, e.g. a change in place of articulation. The term "categorial", as Keating calls it, is rooted in abstract phonological principles rather than phonetic concepts. When referring to the nature of phonological or phonetic rules as categorial (or categorical, in Kiparsky's (1985) usage) vs. gradient, I will use the terms discontinuous and continuous, respectively, as I feel they are acoustically and perceptually more appropriate.

Opposed to this characterization is a phonetic rule, for which definitions are considerably more diverse. Nord (1975) shows how allophonic variation resulting from coarticulation of reduced vowels in Swedish can best be explained as discontinuous phonetic processes without resorting to phonological descriptions. This kind of phonetic rule explains phonological variation from a phonetic perspective.

Keating (personal communication) characterizes phonetic rules as gradient ones in which only certain segmental attributes are affected. One example of how a
rule operates in this kind of gradient fashion is phonological neutralization: the merger of a contrast in certain contexts. Drawing on instrumental studies of phonological rules in a number of languages, Dinnsen (1985) found systematic differences in production which corresponded with underlying distinctions. To cite an example from German, in which word final obstruents are putatively devoiced, Port et al. (1981) found vowel durations before underlying voiced obstruents to be longer (by approximately 10%) than their counterparts preceding underlying voiceless obstruents. Furthermore, underlying voiced obstruents showed somewhat more voicing into the consonant closure, and there was also a significant difference (of approximately 15 msec.) in aspiration duration of word-final underlying voiced and voiceless obstruents. Yet there was no significant difference in closure durations of underlying voiced and voiceless obstruents (Dinnsen, 1985, p. 267). Clearly, speakers employ a number of unexpected parameters in what is a gradient, rather than a categorial, rule.

It should be noted that some of the studies Dinnsen cites have been criticized as artifactual. Charles-Luce (1987), in a perceptual study of voicing in word-final Catalan stops, found that neither Catalan nor English listeners were able to identify underlying voicing at levels significantly above chance. She found that although vowel duration significantly distinguished
underlying voicing in two-sentence medial position, this effect was not present in sentence-final position. She thus concluded that any acoustic differences between the underlying voice contrasts had no perceptual salience.

This is coupled with evidence from various other sources (see, for example, Crystal and House, 1982), that minimal pairs elicited in junctural studies often create artifacts.

Another discussion of gradiency, or the continuous nature of phonetic rules, is presented in Liberman (1983) and Liberman and Pierrehumbert (1984) in the context of postlexical rules. These claims will be examined in more detail in the following chapter's discussion of Postlexical Phonology.

In this dissertation I hope to incorporate several of the above perspectives. I hope to show how inter-word palatalization has both the discontinuous component of its word-internal counterpart, as well a continuous, durational, component resulting from its status as an inter-word rule.

1.2 Outline

The following is an outline of the contents of this dissertation.

Chapter Two will discuss the nature and existence of phonetic rules as they are accounted for in the phonological literature. I will first present a brief
review of how junctural rules are treated in contemporary phonological theory, specifically Lexical Phonology. I will then examine the status of word-boundary rules in the acoustic-phonetic literature, also examining how this information has been used in word-parsing strategies. Chapter Three will present an acoustic-phonetic study of inter-word palatalization.

A discussion of the experimental results and their implications for theories of inter-word phonetic rules will be presented in Chapter Four.
Chapter 2

Word Boundaries in Phonological and Phonetic Research

In this chapter I will examine the status of word boundary rules in Lexical Phonology, and discuss attempts by some researchers to look at these theories experimentally. I hope to show the usefulness of these kinds of studies for further development of phonological theories of word boundary rules.

I will also review a number of experimental studies of the effects of word boundaries on phonetic variation, as well as examine how knowledge of phonetic and phonological variation at word boundaries has been exploited in speech recognition systems.

2.1 Word Boundary Rules in Lexical Phonology: A Brief Review

The status of word boundary rules in the grammar has always been controversial. It has alternately been viewed as phonetic (Trubetzkoy, 1969), phonemic (Trager and Bloch, 1941), morphophonemic in character (Hooper, 1976), and as part of the phonological component of the grammar (Mohanan, 1986; Kiparsky, 1982). In this subsection I will examine the status of sandhi rules in Lexical Phonology, the current phonological theory most concerned with allophonic variation triggered by the syntactic component of the grammar.

Early writings on Lexical Phonology (Pesetsky 1979;
Kiparsky 1982) assume two kinds of phonological rules which constitute disjoint sets: lexical and postlexical rules. But later writings (Mohanan, 1986) distinguish between different kinds of rule applications rather than rules themselves. Rules can apply exclusively in the lexical or in the postlexical domain, but there are also rules that can apply in both.

Lexical rules, Mohanan (1986) notes, are distinguished from postlexical rules by a number of factors. One is cyclicity: lexical rules (which apply in the lexicon) apply cyclically, whereas postlexical rules are noncyclic.

The concept of cyclicity in Lexical Phonology is tightly bound to that of strata, or levels, which was developed to represent the interdependency of phonological and morphological processes. Assuming that phonological rules apply inside the lexicon, the observation that blocks of morphemes trigger certain sets of phonological rules can be explained by reference to strata: the output of a stratum of word formation is submitted to those phonological rules assigned to the relevant stratum in the lexicon (Pulleyblank, 1986, p. 2).

The cycle, then, accounts for ways in which rules can apply with respect to a particular stratum. As Lexical Phonology is still evolving, there is some disagreement as to the cyclic nature of phonological rules. Early works (Pesetsky, 1979; Mohanan, 1982, and Kiparsky 1982) assume phonological rules apply to the output of every
morphological process. However, later works (Halle and Mohanan, 1985; Mohanan and Mohanan, 1984) propose that for certain strata, phonological rules apply cyclically, while for others they do not (Pulleyblank, 1986, p. 3). Whether or not the rule applies cyclically or non-cyclically is dependent on the concept of the strict cycle, that a rule may apply on any given cycle only if its structural description has been derived on that cycle (Pulleyblank, 1986, p. 3).

Mohanan (1986) proposes that the main distinguishing feature of rules applying in the lexical module is their sensitivity to morphological information (p. 8). For example, rules like English trisyllabic shortening and velar softening require morphological information, while rules which may apply in the postlexical module, such as aspiration and flapping, do not. In regard to application of rules across lexical boundaries, he states that they take place postlexically. Thus, a rule such as palatalization of fricatives may be considered a lexical application when occurring within a word, as in the word "racial", but applies postlexically in "miss you".

Several other concepts are involved in distinguishing lexical from postlexical rules. Pulleyblank (1986) cites Mohanan (1982) in claiming that a rule's ability to have lexical exceptions is reserved for lexical rules only. Postlexical rules may not have lexical exceptions. He also
notes Kiparsky's (1982) observation that lexical rules are subject to structure-preservation constraints, e.g. if a language prohibits syllables with a branching rime, then lexical rules in this language cannot create one. However, postlexical application of rules permit syllables that do not appear in lexical representations.

Pulleyblank (1986) thus summarizes the properties of rules applying lexically and those applying postlexically as follows (p.7):

Lexical

a) may refer to word-internal structure
b) may not apply across words
c) may be cyclic
d) if cyclic, then subject to strict cycle
e) structure-preserving
f) may have lexical exceptions
g) must precede all post-lexical rule applications

Postlexical

a) cannot refer to word-internal structure
b) may apply across words
c) cannot be cyclic
d) non-cyclic, hence across-the-board
e) need not be structure-preserving
f) cannot have lexical exceptions
g) must follow all lexical rule applications

But a number of researchers have recently shown there to be certain phonetic phenomena that have previously been
considered low level variation but in fact act in a language-particular manner, e.g. intonation in English (Liberman and Pierrehumbert, 1984), vowel-to-vowel coarticulation in Russian and English (Keating, 1985), and vowel length distinction between flaps with differing underlying representations in English ("writer" vs. "rider") (Anderson, 1975), to name a few. The question they raise is how these phonetic rules are to be accounted for in the grammar.

Liberman and Pierrehumbert (1984) propose that the phonetic component may be equivalent to the postlexical one: that "nontrivial, (partly) language-particular phonetic interpretation should take over the function of most postlexical phonological rules" (p. 232). Thus, all postlexical rules are phonetic implementation rules. Liberman (1983) distinguishes phonetic from phonological rules in four ways, one of which involves the use of the concept of binary, or categorial, vs. non-binary, or gradient, features. As mentioned in Chapter 1, I prefer the use of the terms "discontinuous" and "continuous". However, when summarizing Liberman's argument I will adopt his terminology.

Liberman's distinctions between phonetic and phonological rules are as follows:

1) phonological rules are restricted to the binary use of features; phonetic rules involve the gradient use of
features;

2) the number of phonological entities is bounded, while the number of phonetic entities is in principle unbounded;

3) the consequences of phonetic rules often involve matters of temporal structure and coordination;

4) phonetic rules cannot have lexically-conditioned exceptions.

The fourth distinction is identical to Pulleyblank's description of postlexical rule application (f) above. Otherwise, these principles distinguishing phonological from phonetic rules do not address the above descriptions of postlexical rules.

Mohanam (1986) attempts to reconcile the two approaches by incorporating this kind of phonetic variation completely into the phonological component of the grammar. He posits two submodules within the postlexical module, one being the syntactic submodule, the other the postsyntactic submodule. The former is comprised of syntactic and phonological rules and has lexical representations as input, while the latter is the submodule of phonetic implementation, with phonological phrases as input and phonetic representations as output.

Pulleyblank (1986) and Kiparsky (1985) propose a more moderate stance. Pulleyblank (p. 8) offers a weaker version of Liberman and Pierrehumbert's claim by incorporating a phonetic component into the grammar as
follows: words are derived in the lexicon and then scanned by the phonology. After lexical insertion at the syntactic level, the syntactic phrase is scanned by the phonology. The phonologically interpreted output of the syntax is then passed on to the phonetic component. Thus the interpretive function of the phonetic component is encoded into the model by having as its input the final output of the postlexical phonology.

Kiparsky (1985) agrees that the distinction between postlexical phonological rules and phonetic processes is far from clearcut. He addresses the continuous/discontinuous dichotomy by suggesting that the distinction between the two may be to some extent how the rules apply rather than their inherent content. Continuous processes cannot automatically be discarded from the phonology, as they sometimes also apply in a discontinuous fashion on the lexical level. Thus, their continuous nature may be predictable as a property of the postlexical application of the rule, while their discontinuous nature would be predictable from their lexical application.

One example Kiparsky offers of a single rule applying differently on lexical and postlexical levels is that of assimilation of nasals in English. He claims that when applied lexically the rule is obligatory, confined to 'feet', and transfers major points of articulation only.
When applied postlexically, the rule is optional, is not affected by stress, and "transfers the exact place of articulation of the following consonant" (p. 86), although what he means by contrasting major points of articulation to exact places of articulation is not clear.

If a rule applies both lexically and postlexically, Kiparsky argues, it may operate on a different set of inputs. It may thus yield a different set of outputs because of the principles of underspecification and Structure Preservation, which determine that any rule introducing lexically non-distinctive features, such as aspiration or glottalization in English, must be postlexical.

It should be noted here, however, that the notion of non-distinctiveness is poorly understood. For example, although aspiration is claimed by Kiparsky (and others) to be phonologically non-distinctive in English, it has been shown to be perceptually distinctive (Abramson and Lisker, 1970).

Kiparsky offers some tentative generalizations about when postlexical rules will function categorically and when they will function in a gradient manner (p. 94):

1) context-sensitive rules which override lexical marking conditions have gradient outputs;
2) rules (usually context free) which assign default values have categorical outputs;
3) rules which assign lexically markable features are
normally categorical, but in some cases the process is really gradient articulatorily but perceived as categorical.

For Kiparsky the crucial difference between postlexical rules that function as phonological, feature changing operations and ones that function as rules of phonetic implementation are whether they respect or break the lexical marking conditions of the language.

As an example of a phonetic rule overriding lexical marking conditions, Kiparsky cites optionally voiceless sonorant allophones in words such as c[r]y, p[l]ay and sp[l]it. In English, sonorants are as a rule voiced, but when they appear as voiceless variants, the output is variable and continuous; that is, the sonorant may be only partially voiceless.

Kiparsky's third generalization is a good example of why theoretical considerations alone cannot resolve these issues. By its very nature the concept of continuous postlexical rules calls for an experimental approach, as it often deals with subphonemic distinctions. Yet few researchers have attempted this integrative approach. Further experimental studies along the lines of Liberman and Pierrehumbert's (1984) "hybrid" study of intonation would shed additional light on the nature of word boundary processes.

Some work along these lines has already been
attempted. In a critique of Natural Generative Phonology (NGP), Devine and Stephens (1980) examine a number of phonetic studies pertaining to word boundary effects, with interesting results. In it they counter the claims of NGP that word boundaries are morpho-syntactic rather than phonological phenomena. Briefly, they point out that numerous low-level allophonic variations at junctural boundaries demonstrate behavior more phonological than morphological. An example is the production of /t/ allophones in various languages, whose "...uniform and continuous nature ...suggests a uniformity of the processes producing it... The non-arbitrary nature of the phonetic phenomena involved is more suggestive of phonologically motivated processes than of morphologized rules" (pp. 72-73).

Before testing some of the claims of Liberman and Kiparsky regarding the status of phonetic and postlexical rules, I will first examine how word boundaries are analyzed in the phonetic literature. The situation there is the reverse of that in phonological theory. While phonologists sometimes theorize to the exclusion of experimental data that might substantiate their claims, phoneticians sometimes study the mechanisms of word boundaries with insufficient interest in their implications for a theory of the speech code (a few notable exceptions are the collective works of Lehiste and Gårding).
2.2 Phonetic Studies of Word Boundary Effects

The driving force behind many of the phonetic studies of word boundary effects has been improvement of existing speech technology. A good deal of research in the early to mid 1970's was directed toward maximizing naturalness and intelligibility of synthesized speech, and therefore focused on two areas: 1) the qualitative effects of word boundaries, or the identification of allophonic variants and their loci in the word, and 2) the quantitative word boundary effects, or the durational properties of segments at lexical boundaries.

From the mid 1970's onward, a good deal of research spawned by technological concerns shifted focus to problems related to the machine recognition of speech. Researchers evinced a greater interest in coartulatory processes as they related to word boundaries, and in general realized the necessity of superimposing higher-order knowledge on interpretation of the acoustic signal. As Withgott (1987) points out, imposing order on the lack of constancy in spoken language calls for a knowledge of phonological rules. These rules, for example, may permit the deletion of all cues to a segment's identity, as when the first syllable of the word "phonetics" is realized as a sustained fricative, with no hint of a vowel; \[\text{phneiks}\] (see also Zue 1982, 1985 for the usefulness of linguistic information in automatic speech recognition).

Although a good deal of interesting phonetic research
has centered on perception of word boundaries and the salience of allophonic cues for word juncture, I choose to concentrate on acoustic-phonetic studies of word boundary effects. Many of these studies were part of twin production and perception studies (for examples, see Klatt, 1976), and their usefulness in this context is self-evident. Yet that does not undermine the importance of acoustic-phonetic studies in their own right. For the speech technology researcher they are a necessary component of understanding and parsing the speech signal, and to the phonologist they can verify or contradict theoretical models, assuming these models are based at least partly on production phenomena.

In the following I will review the literature on phonetic studies of qualitative and quantitative aspects of word boundary effects, as well as phonetic studies of coarticulatory processes as they are affected by lexical constraints. I will also look briefly at how some of these qualitative aspects of word boundary effects have been utilized in speech recognition systems.

2.2.1. Qualitative Effects of Word Boundaries

2.2.1.1. Acoustic-Phonetic Studies

Although juncture has been well studied in languages other than English (e.g. Garding's (1967) study of Swedish), the following discussion will be limited to studies of American English. Lehiste's (1960)
spectrographic research on juncture examined minimal pairs of words, e.g. "why choose" vs. "white shoes", and found the primary acoustic cues of juncture to be allophonic variation, such as aspiration, glottalization, or the presence of velarized /l/ in syllable- or word-final position.

Nakatani and Dukes (1977) confirmed the perceptual relevance of these junctural cues, claiming the strongest junctural cues to be qualitative rather than quantitative. Both Lehiste and Nakatani and Dukes found the main loci of the strongest perceptual and acoustic junctural cues to be at the beginning of words (see Umeda and Coker's (1975) observations below). Lehiste also observed several acoustic cues appearing in word-final position, notably /l/ and /r/ allophones.

While Lehiste's studies focused on junctural distinctions of minimal pairs, Umeda and Coker (1975) examined a corpus of read speech, and found the use of allophonic variation to be similar to that in junctural minimal pairs. For example, they found "clear" and "dark" /l/s as initial and final allophones, and also found the presence of a boundary between /n/ and a vowel to inhibit nasalization of the vowel. They found both qualitative and quantitative allophonic variation to be governed by lexical and sentence stress, word and phrase boundaries and phoneme sequences inside and between words. They claimed that the
qualitative variation they found made initial allophones more consonantal, and medial and final allophones more vocalic, thereby giving the impression of fluency word-internally and between function words, and discontinuity where an important word begins.

For example, they found voiceless stops in word-initial stressed position and in stressed non word-initial position to be the most heavily aspirated, with shorter and less aspirated voiceless stops adjacent to nasals and in function words, while word-medial /t/s were at the bottom of the aspiration group. Similarly, the amplitudes of voiceless fricatives were higher in initial and stressed conditions, and considerably reduced word-medially and word-finally.

Voiced consonants showed a difference in spectral balance between initial and final consonants. For instance, word-initial /d/ showed lower components (lower than 500 Hz) to be stronger than higher components, while word- and phrase-final allophones showed lower components slightly stronger than higher ones. Furthermore, Umeda and Coker found the spectral shape of initial voiced stop allophones to have strong fundamentals and second harmonics, and very weak higher harmonics, while non-initial allophones proved to be richer in higher, more audible harmonics and weaker in fundamentals. In short, they were more vowel-like.
2.2.1.2. Allophonic Variation and Lexical Access

The purpose of Umeda and Coker's research was to formulate simple rules to account for the behavior of phonemes in varying phonological conditions. A number of other studies have attempted to apply qualitative allophonic variation to word parsing strategies for the machine recognition of speech. As part of the ARPA SUR (Advanced Research Projects Agency Speech Understanding Research) Project of the early 1970's, Cohen and Mercer (1975) and Oshika et al. (1975) assumed this variation to be part of the lexical representation of the word, which must somehow be incorporated into the lexical retrieval component.

More recently, Church (1987) proposed a use of qualitative allophonic variation as parsing and lexical retrieval tools. Instead of attempting to directly map acoustic/phonetic segments onto lexical items, he proposed utilizing allophonic variation as an intermediate level between input transcription and output word lattice. In this level, hypotheses about syllable structure and stress domains are made which facilitate the formulation of lexical hypotheses. Once syllable structure is established, the structure is then matched against the dictionary to find word hypotheses.

But before constituents are looked up in the dictionary, Church claims, a canonicalization process is
applied which undoes allophonic rules, leaving the segment with only its distinctive features. Here Church assumes the Lexical Phonology position that allophones are generated solely by postlexical, rather than lexical, rules: he notes that since postlexical rules do not operate on words, as they cross word boundaries, they must operate on some other level of representation. This conclusion is supported by findings of Umeda and Coker (1975) and Klatt (1976), among others, which show the sensitivity of allophonic variation to suprasegmental factors.

Another approach to utilizing allophonic variation at word boundaries is a probabilistic approach. Weintraub and Bernstein (1987) describe a recognition lexicon for speaker-independent continuous speech recognition. It consists of probabilistic pronunciation networks that model the phonetic variations observed in connected speech. They include the generation of inter-word phonological effects when phonological rules are applied to individual word models. This probabilistic approach to allophonic variation is mirrored in the experimental phonetic literature by, e.g. Cooper et al. (1978, 1983), who examined factors affecting the probability of occurrence of stop-glidel glide palatalization across word boundaries and found syntactic structure, emphatic stress and frequency of word usage all to play a role in application of this optional rule.
2.2.2. Quantitative Effects of Word Boundaries

Klatt (1976) and others have shown segmental timing to carry a high functional load in English. A number of studies have examined the influence of word boundaries on segmental durations. Some looked at the influence on duration of segment position in the word. While word-final syllables were found to be somewhat longer than others, even in non-phrase final position (Oller, 1973; Klatt, 1975), word-final lengthening was not found by all investigators (Harris and Umeda, 1974). From these studies, Klatt (1976) surmised that the effect was probably too small to contribute significantly to the decoding of word boundary locations.

On the other hand, Beckman and Edwards (in press) did find evidence of final lengthening at both intonational phrase boundaries as well as word boundaries. While the former effect was stronger and more robust than the latter, they found final lengthening at edges of actual lexical items that occurred independent of stress and accent.

Position of stressed syllables in the word did, however, influence consonantal duration (as well, of course, as duration of the stressed vowel). A number of studies found prestressed consonants longer by 5-20 msec. than others in most phonetic environments (Oller, 1973; Klatt, 1974). Umeda (1977) found stress to account for the variance occurring in consonant durations. Word-
initial, stressed consonants exhibited a larger variance than those in word-medial position. Word-initial, unstressed consonants showed smaller variances, similar to intervocalic ones, with slightly larger standard deviations.

2.2.3. Fricative Durations and Word Boundaries

Several studies also examined duration of a particular segment. Fricative duration was the focus of several studies of segmental duration influenced by juncture. Lehiste (1960) found that in minimal pairs, [s] was usually longer in word-initial position. Examining the minimal pairs "my seat" vs. "mice eat" and "new supper" vs. "noose upper", Klatt (1974) confirmed these results, finding a difference of 16% depending on word-initial or word-final position. He also found [s] duration dependent on whether the following vowel nucleus was stressed or not, but independent of the degree of stress on the vowel. He found it longer in prestressed position and shorter before unstressed vowels and in word-final position. He also found [s] duration to be independent of the position of the syllable in the word. Locations of syllable and morpheme boundaries did not influence the duration of intervocalic [s].

From these observations Klatt proposed two decoding rules: 1) duration is a cue to word boundary location: word boundaries are likely to occur before a long [s] but
not after it, except in prepausal position, and 2) a series of short syllables with very short [s] duration suggests the presence of a multisyllable word. A very long [s] suggests the beginning of a single syllable word. Klatt does not mention that it may also suggest the presence of a geminate consonant.

Although these principles seem plausible, a caveat should be noted when researchers attempt to make generalizations about allophonic variation based on junctural minimal pairs. These kind of studies are likely to promote artifactual results that might otherwise not occur in connected speech when the contrast between specific lexical items is not as obvious.

There is evidence in the literature that durational effects reported in "laboratory speech" (see Chapter 1) do not necessarily show up in studies of connected speech. For example, Crystal and House (1982) point out that studies showing that vowel duration is more or less negatively correlated with the number of syllables in a word have used nonsense utterances (Lindblom, 1973), isolated words or short phrases (Barnwell, 1971) or words in a carrier phrase (Klatt, 1973). However, Umeda (1975) did not find evidence of this effect in connected speech materials, and Harris and Umeda (1974) found this effect to be negligible in connected speech.

Nevertheless, this caveat is counteracted by those
studies which employed connected speech and did find evidence of durational variation at word boundaries, e.g. Beckman and Edwards (in press). In the following chapter I will show that affricates as well as fricatives exhibit temporal sensitivity to word boundaries, as do certain palatalized allophones.

2.3 Coarticulation Across Word Boundaries

There is a substantial literature on acoustic studies of coarticulation, much of it oriented toward the goal of formulating a model of speech production. Kent and Minifie (1977) critique many of these models which, they claim, do not acknowledge the hierarchical structure evidenced by coarticulatory processes. They argue persuasively that coarticulatory patterns can only be explained by modelling speech hierarchically. They propose several basic components: rhythmic grouping of syllables, syllable shapes and associated syllabic rules, phonemes or segments, sets of phonetic features, the articulatory realization of these features, and the sequence of neuromotor commands.

Thus, while some phoneticians acknowledge a higher order structuring of coarticulatory events, only a relatively small portion of the literature deals with coarticulation as it occurs across lexical boundaries. Many of these studies are of languages other than English (e.g. phonetic studies of inter-word voicing assimilation in Dutch by Slis (1983, 1984, 1986)). Unfortunately, of
the studies involving English, the majority are marred by poor methodology and artifactual results.

Two articulatory studies of higher order constraints on coarticulation were performed by McLean (1973) and Hardcastle (1985). The former is a cinefluorographic experiment examining anticipatory coarticulation of velar movement in CVVN sequences, the latter an electropalatographic study of lingual coarticulation duration /kl/ sequences. Both found a distinct lack of coarticulation at higher syntactic boundaries (phrase, clause, sentence) at normal rates of speech, and a greater degree of coarticulation at these boundaries at fast rates of speech.

McLean attributed his results to input commands to the velum at higher level boundaries. Hardcastle generally concurred with these conclusions, adding that the principal constraint operating on the degree of coarticulation is perceptual: the lack of coarticulation at major prosodically marked syntactic boundaries shows that segments freely coarticulate except when there might be a perceptually significant constraint. Hardcastle found some coarticulation between initial clusters, and even more coarticulation at syllable boundaries within a word and sometimes at word boundary, which he attributed to mechanical factors: greater oral pressure and subsequent air-flow at release of initial clusters making it relatively more difficult to raise the
tongue tip rapidly for alveolar closure. However, there is no buildup of oral pressure for velar stops: the oral pressure should be equal to the atmospheric pressure. This lessens the plausibility of Hardcastle's conjecture.

These studies share two flaws in their methodology which cause their results to be regarded as largely artifactual or spurious. The first is the data that is collected. Sentences which contain phrase, clause or sentence boundaries are marked with commas or periods, which presumably were implemented by speakers as a pause. Naturally the segments preceding and following the pause would not show much coarticulation: there was adequate time for articulators to "get into place".

The second factor shared by both studies is the method of collecting data. The hardware required for articulatory studies might possibly introduce artifactual results in the speech of subjects.

2.3.1. Experimental Studies of Palatalization

There have been several experimental studies of phonologized coarticulatory, or assimilatory, rules in English that, despite their limitations, have raised interesting ideas for further research. The studies in which I am most interested are those dealing with palatalization across word boundaries.

In two studies of across word palatalization of stops by glides, Cooper et al. (1978, 1983) found the rule to be
sensitive to speech rate and to prosodic information. Specifically, palatalization was more likely to occur at faster rates of speech, and in the absence of emphatic stress at the relevant words. It also seems to be promoted when the word beginning with the glide is "you", "your", "yours" or "yourself": all words with a high frequency of occurrence. The frequency effect, however, may not delimit the occurrence of the rule, as Zue and Shattuck-Hufnagel (1980) attest to it occurring in such low frequency utterances as "sweet Yosemite", although they cite no sources for this information.

Kaisse (1985) rejects classifying palatalization as a strictly prosodic (or fast speech) rule because so many words beginning with yod could not trigger palatalization, even when they do meet the prosodic criteria for application of the rule, e.g. "*He's my thir[j] urologist in as many months"" (p. 37). She concludes tentatively that frequency of the yod word may override prosodic considerations, thus making palatalization a rule that had its origins in the constraints of fast speech, but which takes grammatical conditions into consideration as well.

Kaisse's approach is inherently unsatisfactory in that it admits that palatalization may have arisen from phonetic considerations but it does not try to examine how these factors influence the rule. Zue and Shattuck-Hufnagel (1980) and Shattuck-Hufnagel et al. (1978) conducted
phonetic studies of palatalization of alveolar fricatives across word boundaries, focusing on the issues of the phonetic contexts which allow palatalization and the acoustic consequences of palatalization on the fricatives. Although the goal of the study was to model the process in psychological terms by first understanding the articulatory mechanisms involved, it is unclear why the researchers chose an acoustic-phonetic study rather than an articulatory one. Some of their phonological conclusions are incomplete: they claim alveolar fricatives can be palatalized only anticipatorily (as in "gas shortage" -\( \rightarrow [g\ae f\text{or}\acute{c}\ae d\text{g}] \)), but completely neglect those cases when it occurs perseveratively, when the palatalized fricative is part of a fricative-stop cluster (as in "fresh strawberries" -\( \rightarrow [f\text{r}\acute{e}st\text{r}o\text{b}\text{e}\text{r}i\text{z}] \) (see Oshika et al., 1975, for spectrographic evidence; also see Chapter 4 for a discussion of another phonological interpretation of this rule).

Nevertheless, their acoustic findings are interesting: for most speakers, palatalized fricatives have substantially similar spectra to their singleton counterparts, but less so when the fricative is palatalized by a yod (they ignore the possible explanation that this may be the result of coarticulation with the yod that optionally remains, as in "miss you" -\( \rightarrow [m\text{iss}\{j\}u] \). Furthermore, their findings that the durations of palatalized sequences are more geminate-like than
singleton-like also merit further exploration.

In Section 2.1, I examined how Kiparsky (1985) incorporated Liberman's (1983) claim of continuous rules into a phonological description of postlexical rules by suggesting that rules are discontinuous when applied lexically, and continuous when postlexical. He does not, however, address Liberman's claim that "the consequences of phonetic rules often involve matters of temporal structure and coordination", which implies that the consequences of phonological rules do not. Many of the studies in Section 2.2 show temporal factors of sandhi-conditioned allophones to be influenced by suprasegmental factors. However, Zue and Shattuck-Hufnagel's experiments on palatalization of fricatives indicate variation in segmental duration may be controlled by discontinuous, phonological rules: that durational factors might be integrated into part of the phonological description.

In the following chapter I will describe an experimental approach that tests certain claims about the nature of these assimilation rules. Specifically, I will look for acoustic evidence of the discontinuous nature of inter-word palatalization as a feature-changing rule. I will also examine the durational properties of palatalized sequences to find support for Liberman's claim of temporal structure as well as Kiparsky's claim of the continuous nature of postlexical rule application. Examining the
The acoustic-phonetics of palatalization across words will clarify the interaction of discontinuous and continuous factors in the production of the rule.
Chapter 3
Three Acoustic-Phonetic Experiments on Inter-Word Palatalization

This chapter presents three experiments that test various hypotheses about the nature of across-word palatalization in English.

EXPERIMENT 1
Introduction

Experiment 1 tests the hypothesis that inter-word palatalization is a discontinuous rule. If it is, then assimilation of place of articulation is complete. On the other hand, if it acts as a continuous rule, then one should find transitions into an alveolar place of articulation. Specifically, it is hypothesized that the formant transitions into the closure portion of the affricate will be identical to those into a palato-alveolar affricate, and will not resemble transitions into the underlying alveolar place of articulation.

Methods
1. Speakers

The speakers were eight male native speakers of American English, all but one of whom were enrolled in the introductory phonetics course at the University of California at Berkeley. All but one were between the ages of 19 and 28 and had grown up in the western United States. The remaining speaker, JL, was in his forties and grew up
on the East Coast. Only he distinguished [a] and [ə]. None of the speakers had a history of speech or hearing problems (see Table 3.1).

Table 3.1

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Age</th>
<th>Place of Birth</th>
<th>Grew Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>44</td>
<td>New York City</td>
<td>N.Y.C./California</td>
</tr>
<tr>
<td>AH</td>
<td>19</td>
<td>New Jersey</td>
<td>Hawaii</td>
</tr>
<tr>
<td>CK</td>
<td>19</td>
<td>France *</td>
<td>California</td>
</tr>
<tr>
<td>FP</td>
<td>22</td>
<td>California</td>
<td>California</td>
</tr>
<tr>
<td>DE</td>
<td>19</td>
<td>Connecticut</td>
<td>California</td>
</tr>
<tr>
<td>WT</td>
<td>25</td>
<td>California</td>
<td>California</td>
</tr>
<tr>
<td>SM</td>
<td>28</td>
<td>Illinois</td>
<td>various states</td>
</tr>
<tr>
<td>LH</td>
<td>20</td>
<td>California</td>
<td>California</td>
</tr>
</tbody>
</table>

* moved to U.S. in infancy

2. Data Corpus

2.1 Test Words and Control Words

The corpus consisted of two parts: control utterances and test utterances. The control utterances contained test words with (1) a geminate alveolar stop, e.g. "did Denise", to provide instances of formant transitions into alveolars (a geminate stop was chosen to block flapping); (2) a palatal fricative, to provide an example of formant transitions into a palato-alveolar place of articulation, and (3) a palato-alveolar affricate, to give transition
values into palatal affricates and also to provide durational measurements for closure and fricovation portions. The test utterances contained words in which palatalization would optionally apply. With the exception of (2) above, every utterance with test words involving voiced stops or affricates had a voiceless stop or affricate counterpart.

2.2 Segmental and Syllabic Controls

Segmental and syllabic factors were also taken into consideration. Utterances with test words having voiced stops and affricates used the vowel [I], and those with voiceless stops and affricates the vowel [a].

These vowels were chosen for two reasons. One is that they were monophthongs. Second, [I] was considered less subject to dialectal variation than other vowels which might have offered more robust transitions. For example, many dialects collapse [æ] and [ɛ]. [a], on the other hand, was chosen for its relatively robust transitions. The fact that certain dialects do not distinguish [a] and [ɔ] was controlled for by asking each subject where he had grown up and which part of the country his parents were from.

An effort was made to maintain a similar number of syllables in all utterances. Test words were preceded by one syllable and followed by 2–3 syllables. The test words themselves contained a stressed syllable followed by an unstressed syllable, with the exception of (1b.)
2.3 Utterances

The utterances were as follows (test words underlined):

Subset A: \( V = [I]; C = [ + voice] \)
Subset B: \( V = [a]; C = [ - voice] \)

CONTROL

(1.)
  a. Why \textit{did Denise} do that?
  b. She \textbf{bought} \textit{Timothy} a bouquet.

(2.) I'll \textit{dish it} out later.

(3.)
  a. Those \textit{digits} might be false.
  b. He'll \textit{botch it} too, I think.

TEST

a. Why \textit{did you} do that?

b. He \textbf{bought you} two bouquets.

2.4. Presentation of Corpus to Speakers

The corpus consisted of 5 repetitions each of the control sentences and 10 repetitions of each test sentence. They were presented to speakers in pseudo-random order with six filler sentences divided between the beginning and end of the test session. The sentences were divided into three blocks, the first one being a dummy session. Half the speakers read the test blocks in one order, the other reversed the order of the blocks.
3. Experimental Procedure

3.1. Recording

After first familiarizing themselves with the corpus, speakers were instructed to read the utterances in a natural manner, at a conversational, i.e. fairly quick, tempo. They were instructed to put emphatic stress on the word "did" in both of the sentences in which they occurred so as to avoid a reduced vowel which would otherwise result.

Speakers were recorded in two sessions. Speakers JL, CK, AH, DE, FP and LH participated in the first session. All but one (LH) then returned for a second session to collect data for Experiments 2 and 3. During this time they recorded utterance 3a with the word "digits" receiving emphatic stress. In this way, durational measurements of the affricate in the word "digits" and in the sequence "did you" would be equivalent in regard to their stress value. Speakers WT and SM attended one session only, during which they recorded the corpora of all experiments in one sitting.

3.2. Equipment

Recordings were made in a sound treated room onto a Technics cassette recorder, and were later normalized and digitized using a 6.4 kHz low pass filter and a 16kHz sampling rate.

Digitization and transcription of waveforms was
performed on the Speech and Phonetics Interactive Research Environment: SPIRE, implemented at M.I.T.

3.3. Transcription

The task of transcribing, or marking, the segments to be measured is a particularly thorny one, for one is in essence imposing discrete units on a continuous entity.

Utterances were first marked by hand on SPIRE, using a combined display of spectrogram, highly detailed waveform (window display magnified to 0.05 sec.), and sound playback. To capture subphonemic detail, the following symbols were added to those already provided in SPIRE: [\textsuperscript{\textdagger}] = fricated voicing during closure, as sometimes appeared in the closure portion of the voiced affricate in "digits"; [-] = slight frication during closure portion of voiceless affricate in "botch it"; [+] = glottalized closure that sometimes appeared in "bought you"; and [h] = aspiration in the word initial [t] of "bought Timothy".

Only the following parts of the test words were transcribed: in the test utterances and in control utterances 3a. and 3b., the vowel of word 1 (V1), e.g. [I] in "did you", closure, release (when present) and frication of palatalized sequences and affricates, and the following vowel (V2). In control utterances 1a. and 1b. the vowel of word 1, the control and release of the stop consonant, and the following vowel were marked, and in control utterance 2 the vowel of word 1, the fricative and the following vowel

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were transcribed.

3.3.1. Temporal Markers

The following guidelines for temporal markers were set up: V1 onset was marked at the beginning of periodic voicing, corresponding to the magnified waveform display. When marking V1 offset, an additional display of the LPC formant trace was employed, and the boundary was marked in conjunction with formant trace, waveform and spectrogram (see Figure 3.1). This was intended to circumvent potential discrepancies between the formant values during vowel transitions reported by users of databases such as DARPA TIMIT, in which phoneme boundaries were aligned automatically rather than marked by hand. Acoustic vowel boundaries are notoriously ambiguous, as the transitions often suffer distortions such as glottalization. In the majority of cases, the formant trace coincided with the region of a viable boundary. In the few instances where this was not so, if the difference between formant trace boundary and waveform boundary were small, e.g. approximately a glottal pulse, the boundary was marked according to the formant trace. If the difference was large, e.g. the entire transition, this was judged to be an error in the LPC analysis, and the boundary was marked according to the waveform. In these few cases, the formant trace was considered errorful and therefore discarded for formant transition analysis, as were all utterances with
abrupt discontinuities in the trace. These utterances, were, however, included in durational analysis.

The above hand-marking methodology was considered the most sensitive means of minimizing durational artifacts while at the same time maximizing formant transition information.

Although these guidelines applied to transcriptions of all utterances, further guidelines were required in the transcription of the test utterances, namely whether or not they should be considered palatalized. It was decided that the speech signal itself should be the primary criterion of this binary decision, in conjunction with auditory judgments by the experimenter. Tokens exhibiting frication after the stop closure were considered palatalized, and the experimenter's auditory judgments corroborated this. The sole instance where the two criteria were not in agreement was speaker FP, for whom many tokens with frication after the closure sounded more like a fricataed stop release than actual frication. These tokens were marked as palatalized, however, and in the analysis of results below did not differ significantly from those of other speakers.

3.4. Analysis of Spectral Information

LPC traces of F2 and F3 were obtained for all tokens by using the SPIRE second and third formant attributes (see 3.3.1. above).
F2 and F3 traces were sampled at endpoint and for approximately 50-60 msec. prior to vowel offset at 5 msec. intervals, and then averaged per speaker over each utterance type. This information was then plotted. Figure 3.2 shows the plot of the F2 and F3 transitions of the five repetitions of "They bought ships for the fleet" by speaker SE. Table 3.2 presents results in table form. In this way, differences in transition durations caused by variation in vowel quality can be diminished, and salient transitional information preserved.

Table 3.2

Experiment 1: Mean F2 and F3 Transitions for Speaker SE

Test Words = "bought ships"; N = 5; Window Size = 5 ms

<table>
<thead>
<tr>
<th>Average F2</th>
<th>SD</th>
<th>Slope</th>
<th>Average F3</th>
<th>SD</th>
<th>Slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1489.00</td>
<td>19.61</td>
<td>1.24</td>
<td>2697.00</td>
<td>19.61</td>
<td>2.48</td>
</tr>
<tr>
<td>1481.80</td>
<td>30.37</td>
<td>3.72</td>
<td>2684.60</td>
<td>15.18</td>
<td>7.44</td>
</tr>
<tr>
<td>1463.20</td>
<td>36.16</td>
<td>4.96</td>
<td>2647.40</td>
<td>24.82</td>
<td>3.72</td>
</tr>
<tr>
<td>1438.40</td>
<td>24.80</td>
<td>4.96</td>
<td>2628.80</td>
<td>23.19</td>
<td>4.96</td>
</tr>
<tr>
<td>1413.60</td>
<td>31.61</td>
<td>6.20</td>
<td>2604.00</td>
<td>39.21</td>
<td>1.24</td>
</tr>
<tr>
<td>1382.60</td>
<td>31.61</td>
<td>3.72</td>
<td>2597.80</td>
<td>36.15</td>
<td>6.20</td>
</tr>
<tr>
<td>1364.00</td>
<td>43.84</td>
<td>3.72</td>
<td>2566.80</td>
<td>23.19</td>
<td>3.72</td>
</tr>
<tr>
<td>1345.40</td>
<td>31.61</td>
<td>7.44</td>
<td>2548.20</td>
<td>23.21</td>
<td>2.48</td>
</tr>
<tr>
<td>1308.20</td>
<td>36.15</td>
<td>2.48</td>
<td>2535.80</td>
<td>36.15</td>
<td>2.48</td>
</tr>
<tr>
<td>1295.80</td>
<td>45.56</td>
<td>4.96</td>
<td>2523.40</td>
<td>24.81</td>
<td>1.24</td>
</tr>
</tbody>
</table>
Results

Results for subset A (vowel = [I]; stop = voiced) and subset B (vowel = [a]; stop = voiceless) are presented separately. Fewer subjects are analyzed in the latter, as only those subjects who applied the palatalization rule were included.

1. Descriptive Statistics

Tables 3.3 and 3.4 show first order statistics of F2 and F3 endpoints. I chose these data as the primary ones to be analyzed because I assumed them to be the most concise indicators of place of articulation, and ones which would also facilitate a statistical analysis.

Table 3.3 represents descriptive statistics for subset A, and those for subset B are presented in Table 3.4.

2. Tests of Significance

2.1 Method of Analysis

Because palatalization is an optional rule, the exact number of repetitions, or N, cannot be predetermined. This present certain complications in analyzing the data. An analysis of variance, or ANOVA, would by necessity be unbalanced (unequal N's in each cell). While an unbalanced ANOVA can present a picture of global effects, it cannot give an accurate description of individual interactions within the cells. However, a detailed analysis of interactions is more desirable than a mere description of
<table>
<thead>
<tr>
<th>Speaker</th>
<th>Control Utterances &quot;did Denise&quot;</th>
<th>Test Utterance &quot;did you&quot; (palat.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>JL</td>
<td>F2</td>
<td>1884.80</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2554.40</td>
</tr>
<tr>
<td>CK</td>
<td>F2</td>
<td>1959.20</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2560.60</td>
</tr>
<tr>
<td>AH</td>
<td>F2</td>
<td>1790.25</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2666.00</td>
</tr>
<tr>
<td>FP</td>
<td>F2</td>
<td>1760.80</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2604.00</td>
</tr>
<tr>
<td>DE</td>
<td>F2</td>
<td>2027.40</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2932.60</td>
</tr>
<tr>
<td>WT</td>
<td>F2</td>
<td>1808.33</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2593.67</td>
</tr>
<tr>
<td>SM</td>
<td>F2</td>
<td>1791.80</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2560.60</td>
</tr>
<tr>
<td>LH</td>
<td>F2</td>
<td>2089.40</td>
</tr>
<tr>
<td></td>
<td>F3</td>
<td>2945.00</td>
</tr>
</tbody>
</table>
Table 3.4

Experiment 1: Formant Endpoints (in Hz) of Control and Test Utterances (Subset B Data)

<table>
<thead>
<tr>
<th>Control Utterances</th>
<th>Test Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speaker</td>
<td>&quot;bought Timothy&quot;</td>
</tr>
<tr>
<td></td>
<td>M</td>
</tr>
<tr>
<td>JL F2</td>
<td>1401.20</td>
</tr>
<tr>
<td>F3</td>
<td>2318.80</td>
</tr>
<tr>
<td>AH F2</td>
<td>1550.00</td>
</tr>
<tr>
<td>F3</td>
<td>2480.00</td>
</tr>
<tr>
<td>LH F2</td>
<td>1587.20</td>
</tr>
<tr>
<td>F3</td>
<td>2622.60</td>
</tr>
</tbody>
</table>

* measurements taken 5 msec. prior to endpoint, as endpoint values showed unacceptable degree of variation
global effects, so for this reason I chose to perform multiple t-tests on the data, using the following formula:

\[
    t = \frac{(M_1 - M_2) - E(M_1 - M_2)}{\text{est. } \sigma_{d, \text{eff.}}} = \sqrt{\frac{\left(\frac{(N_1 - 1) \sigma_1^2 + (N_2 - 1) \sigma_2^2}{N_1 + N_2 - 2}\right)}{\frac{N_1 + N_2}{N_1 + N_2}}}
\]

An analysis of variance of this data would be a mixed model, the random effects component being the effect of individual speakers, and the fixed effects the segmental environment. While random effects models allow one to draw inferences concerning variances, the fixed effects model allows inferences concerning means, which is also accomplished in t-tests. In Experiment 1 I am concerned primarily with differences between mean formant values.

2.2 Analysis of Results

Table 3.5 shows p values for all comparisons made in tests of significance.

2.2.1 Comparison Between Controls

Prior to comparison of test and control words, a comparison was made between the two places of articulation in the respective controls. p values of one-tailed t-tests on alveolar control words and palato-alveolar control words for Subset A data are presented in column 1 of Table 3.5: speakers JL (p = 0.025), AH (p = 0.01), DE (p = 0.025) and SM (p = 0.05) show alveolar endpoints significantly higher than their palato-alveolar counterparts, as expected. The effect is far weaker for speakers WT (p = 0.4) and LH (p = 0.1). Two speakers, CK and FP, showed
Table 3.5

Experiment 1: p Values of F2 Endpoints

<table>
<thead>
<tr>
<th>Speaker</th>
<th>Minimal Pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>JL</td>
<td>0.25</td>
</tr>
<tr>
<td>CK</td>
<td>*</td>
</tr>
<tr>
<td>AH</td>
<td>0.01</td>
</tr>
<tr>
<td>FP</td>
<td>*</td>
</tr>
<tr>
<td>DE</td>
<td>0.025</td>
</tr>
<tr>
<td>WT</td>
<td>0.4</td>
</tr>
<tr>
<td>SM</td>
<td>0.05</td>
</tr>
<tr>
<td>LH</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Legend

Minimal Pair 1: "did Denise" vs. "digits"
Minimal Pair 2: "bought Timothy" vs. "botch it"
Minimal Pair 3: "bought Timothy" vs. "bought you" (palatalized)
Minimal Pair 4: "botch it" vs. "bought you" (palatalized)

* = anomalous
anomalous results in Subset A, with mean alveolar F2 endpoints higher than their palato-alveolar counterparts.

For subset B data (Column 2, Table 3.5), F2 alveolar endpoints are lower than F2 palato-alveolar endpoints to a highly significant degree for speakers JL (p = 0.001) and LH (p = 0.001), while for speaker AH the effect is less strong (p = 0.25).

2.2.2. Comparison Between Test and Controls

Visual comparison of test words to control words in Subset A data (Table 3.3) shows mean F2 endpoints of test words to be higher than those of control words for all speakers.

This was not the case, however, for Subset B data (Table 3.4). Results of non-directional t-tests comparing the mean of test words with control words containing palato-alveolar affricates showed the difference between the means to be strongly significant for speaker JL (p = 0.05) and weaker for speakers AH (p = 0.1) and LH (p = 0.1) (Column 6, Table 3.5).

Comparison of mean F2 endpoints of alveolar controls to palatalized test words show a significant difference for all three speakers, JL (p = 0.001), LH (p = 0.001) and AH (p = 0.02). A post-hoc visual comparison of formant transition plots showed all subjects in subset A to have a greater similarity between test words and control words with a palato-alveolar affricate than between test words
and controls with alveolar stops, thus confirming conclusions drawn by examining the mean formant endpoint values.

Endpoint data for formant endpoints preceding palatoalveolar fricatives was not included in the controls. Upon examination of the data (Table 3.6), I found an unacceptably high degree of variability due to problems of spectral analysis for a number of speakers. Furthermore, I felt comparison between transitions into fricative and into stop place of articulation not be be justified.

**Discussion**

The fact that for Subset A data (vowel = [I]) there is some interspeaker variation as to the strength of the difference between the control words (alveolar vs. palatoalveolar) may possibly be ascribed to vowel quality: [I] transitions are not as robust as those of [a]. This is reflected in comparison of controls in Subset B data (vowel = [a]). Comparing palatalized test words to both alveolar and palato-alveolar controls reflects a discontinuous effect. For Subset A data, all test word F2 endpoints are higher than both controls, possibly due to coarticulation with an optional glide (e.g. [di ʤ(j)]). The fact that in Subset B data, speaker JL does not show the strong discontinuous effect of the other speakers (test words significantly similar to palato-alveolar controls, and only weakly the same as alveolar controls) may be accounted for
Table 3.6

Experiment 1: Formant Endpoints (in Hz) of Control Utterance "dish it"

<table>
<thead>
<tr>
<th>Speaker</th>
<th>M</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL F2</td>
<td>2573.00</td>
<td>n/a</td>
<td>1</td>
</tr>
<tr>
<td>F3</td>
<td>3193.00</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>CK F2</td>
<td>1804.20</td>
<td>66.20</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>2542.00</td>
<td>115.99</td>
<td></td>
</tr>
<tr>
<td>AH F2</td>
<td>1940.60</td>
<td>31.61</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>2746.60</td>
<td>46.39</td>
<td></td>
</tr>
<tr>
<td>FP F2</td>
<td>1821.25</td>
<td>103.69</td>
<td>4</td>
</tr>
<tr>
<td>F3</td>
<td>2557.50</td>
<td>15.51</td>
<td></td>
</tr>
<tr>
<td>DE F2</td>
<td>2399.40</td>
<td>559.93</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>3261.20</td>
<td>732.65</td>
<td></td>
</tr>
<tr>
<td>WT F2</td>
<td>1909.60</td>
<td>334.80</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>2721.80</td>
<td>360.13</td>
<td></td>
</tr>
<tr>
<td>SM F2</td>
<td>1883.25</td>
<td>25.71</td>
<td>4</td>
</tr>
<tr>
<td>F3</td>
<td>2588.50</td>
<td>15.51</td>
<td></td>
</tr>
<tr>
<td>LH F2</td>
<td>2046.00</td>
<td>19.61</td>
<td>5</td>
</tr>
<tr>
<td>F3</td>
<td>2864.40</td>
<td>31.62</td>
<td></td>
</tr>
</tbody>
</table>
by dialectal variation, as he was the sole speaker who
differentiated [a] and [ ]).

As for testing the hypothesis stated in the
Introduction, it can best be answered by claiming that
inter-word palatalized sequences do not show alveolar
second formant endpoints, rather than claiming that they do
show transitions identical to palato-alveolar affricates.
EXPERIMENT 2

Introduction

There is, to my knowledge, no literature on the durational characteristics of affricates in regard to word boundaries. I wanted to see if affricates, like fricatives (Klatt, 1974), show temporal variation due to word boundaries. If so, do affricates resulting from palatalization act as if in word-initial or word-final position, or somewhere in between? Should this last alternative be the case, this would indicate a continuous rule in which palatalization is implemented with a unique duration which is neither word-initial nor word-final.

Three specific hypotheses are tested: (1) Hypothesis 1: durations of inter-word stop + fricative clusters behave differently than those of word-initial affricates; (2) Hypothesis 2: durations of affricates differ depending on whether they are word-initial or word-final; and (3) Hypothesis 3: durations of affricates that are underlyingly stop + glide sequences (palatalized sequences) differ from affricates that are not.

Methods

1. Speakers

The same data as used in Experiment 1 were analyzed in Experiment 2. Additional data were collected from speakers JL, CK, AH, FP and SM during a second recording session. Data were also collected from speaker SE, age 18,
who was born in California and grew up in New Jersey and California.

2. Data Corpus

2.1 Test Words and Control Words

The corpus was the same as that used in Experiment 1, with the following changes: (1) the palatal fricative control "dish it" was omitted; and (2) two utterances were added, one with a word-initial affricate ("gnaw chips"), the other with a stop + fricative cluster at word juncture ("bought ships").

2.2 Segmental and Syllabic Controls

These were the same as for Experiment 1. However, Subsets A and B are assymetrical, partly due to phonotactic constraints, e.g. word-final [I] is not allowed in English. I expect that vowel identity will not play a significant role in implementation of palatalization or in any way skew results.

2.3 Utterances

The utterances were as follows (test words underlined):

Subset A: \( V = [I]; C = [+ \text{ voice}] \)

Subset B: \( V = [a]; C = [- \text{ voice}] \)

CONTROL

(1.) a. Those digits must be false.

(2.) b. She would gnaw chips and snacks all day.
(3.) b. He'll botch it too, I think.

(4.) b. They bought ships for the fleet.

TEST

(1.) a. Why did you do that?

(2.) b. He bought you two bouquets.

2.4 Presentation of Corpus to Speakers

See Experiment 1. The additional control utterances were repeated 5 times, with the repetitions interspersed in pseudo-random order among the utterances for the third experiment.

3. Experimental Procedure

3.1 Recording

See Experiment 1.

3.2 Equipment

See Experiment 1.

3.3 Transcription

See Experiment 1. Three parts of the sequence were measured: (1.) the vowel preceding the surface affricate, (2.) the closure portion and (3.) the frication. These were compared to durations of palato-alveolar affricates in word-final, word-initial and word medial position. It was hypothesized that durations of palatalized sequences would differ from affricates in other positions, and would exhibit unique durational patterns, thus marking them as
junctural phenomena.

For test utterances, those tokens discarded for spectral analysis because of discontinuities in LPC traces were retained for durational analysis. The only test utterances not analyzed were those in which subjects did not apply palatalization.

3.3.1 Temporal Markers

As in Experiment 1, durational measurements were obtained for all transcribed segments by measuring the distance between segment markers.

Results

1. Descriptive Statistics

As in Experiment 1, results for subset A (vowel = [I], obstruent = voiced) and subset B (vowel = [a], obstruent = voiceless) are presented separately. Table 3.7 shows first order statistics for subset A data, while first order statistics for subset B data are shown in Table 3.8. Here, as in all subsequent data, the durational units are seconds, rounded off to the sixth decimal place.

Boxplots showing the distribution of durations of the three components of subset A data (preceding vowel, closure and friction) are in Figures 3.3, 3.3a, 3.4, 3.4a, 3.5 and 3.5a. Boxplots of subset B data are in Figures 3.6, 3.6a, 3.7, 3.7a, 3.8 and 3.8a. These boxplots sketch the distribution of the durations. The line is the median, the box around it the values in which 50% of the data fall, and
the whiskers the upper and lower quartiles.

Table 3.7

Experiment 2: Moments of Utterances "did you"
(Palatalized) and "digits" in Seconds (Subset A Data)

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>9</td>
<td>0.079064</td>
<td>0.000045</td>
<td>0.052921</td>
</tr>
<tr>
<td>CK</td>
<td>10</td>
<td>0.063171</td>
<td>0.000203</td>
<td>0.043960</td>
</tr>
<tr>
<td>AH</td>
<td>7</td>
<td>0.079311</td>
<td>0.000260</td>
<td>0.053304</td>
</tr>
<tr>
<td>DE</td>
<td>6</td>
<td>0.059113</td>
<td>0.00038</td>
<td>0.058972</td>
</tr>
<tr>
<td>FP</td>
<td>4</td>
<td>0.056927</td>
<td>0.00018</td>
<td>0.051972</td>
</tr>
<tr>
<td>WT</td>
<td>10</td>
<td>0.085249</td>
<td>0.00056</td>
<td>0.065331</td>
</tr>
<tr>
<td>SM</td>
<td>4</td>
<td>0.144720</td>
<td>0.000348</td>
<td>0.086885</td>
</tr>
<tr>
<td>LH</td>
<td>9</td>
<td>0.074564</td>
<td>0.00039</td>
<td>0.035530</td>
</tr>
</tbody>
</table>

Moments of Control Utterance "digits" in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>5</td>
<td>0.067998</td>
<td>0.00020</td>
<td>0.036065</td>
</tr>
<tr>
<td>CK</td>
<td>5</td>
<td>0.054811</td>
<td>0.00036</td>
<td>0.037168</td>
</tr>
<tr>
<td>AH</td>
<td>5</td>
<td>0.094149</td>
<td>0.000117</td>
<td>0.045403</td>
</tr>
<tr>
<td>DE</td>
<td>5</td>
<td>0.058660</td>
<td>0.00007</td>
<td>0.034175</td>
</tr>
<tr>
<td>FP</td>
<td>5</td>
<td>0.049540</td>
<td>0.00022</td>
<td>0.030477</td>
</tr>
<tr>
<td>WT</td>
<td>5</td>
<td>0.076491</td>
<td>0.00097</td>
<td>0.059639</td>
</tr>
<tr>
<td>SM</td>
<td>5</td>
<td>0.111903</td>
<td>0.00167</td>
<td>0.049062</td>
</tr>
<tr>
<td>LH</td>
<td>5</td>
<td>0.071001</td>
<td>0.00028</td>
<td>0.033984</td>
</tr>
</tbody>
</table>
Table 3.8

Experiment 2: Moments of Utterances "bought you" and "botch it" in Seconds

Moments of Test Utterance "bought you" (Palatalized) in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>9</td>
<td>.124994</td>
<td>.000058</td>
<td>.035443</td>
</tr>
<tr>
<td>CK</td>
<td>10</td>
<td>.108460</td>
<td>.000043</td>
<td>.039174</td>
</tr>
<tr>
<td>AH</td>
<td>9</td>
<td>.101309</td>
<td>.000122</td>
<td>.053163</td>
</tr>
<tr>
<td>LH</td>
<td>8</td>
<td>.104212</td>
<td>.000009</td>
<td>.020502</td>
</tr>
</tbody>
</table>

Moments of Control Utterance "botch it" in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>5</td>
<td>.134189</td>
<td>.000022</td>
<td>.016548</td>
</tr>
<tr>
<td>CK</td>
<td>5</td>
<td>.108877</td>
<td>.000004</td>
<td>.028534</td>
</tr>
<tr>
<td>AH</td>
<td>5</td>
<td>.107944</td>
<td>.000058</td>
<td>.047540</td>
</tr>
<tr>
<td>LH</td>
<td>5</td>
<td>.106783</td>
<td>.000027</td>
<td>.028847</td>
</tr>
</tbody>
</table>
Figure 3.3

Boxplots: Vowel Duration in Palatalized "did you"

Subjects

JL  CK*  AH  DE  FP  WT  SM  LH*
Figure 3.3a

Boxplots: Vowel Duration in "Digits"

Duration in seconds

Subjects
Figure 3.4

Boxplots: Closure in Palatalized "did you"

Duration in seconds

Subjects

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Figure 3.4a

Boxplots: Closure duration in "digits"

Subjects

JL  CK*  AH  DE  FP  WT  SM  LH*
Figure 3.5

Boxplots: Frication in "did you"

Subjects

JL  CK*  AH  DE  FP  WT  SM  LH*
Figure 3.5a

Boxplots: Duration of Frication in "digits"

Subjects

JL  CK*  AH  DE  FP  WT  SM  LH*
Figure 3.6

Boxplots: Vowel in Palatalized "bought you"

Duration in seconds

JL  CK  AH  LH

Subjects
Figure 3.6a

Boxplots: Vowel in "botch it"

<table>
<thead>
<tr>
<th>Subjects</th>
<th>JL</th>
<th>CK</th>
<th>AH</th>
<th>LH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration in seconds</td>
<td>0.105</td>
<td>0.12</td>
<td>0.135</td>
<td>0.15</td>
</tr>
</tbody>
</table>

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Figure 3.7

Boxplots: Closure in Palatalized "bought you"

Duration in seconds

Subjects

JL  CK  AH  LH
Figure 3.7a

Boxplots: Closure in "botch it"
Figure 3.8

Boxplots: Frication in Palatalized "bought you"

Duration in seconds

JL  CK  AH  LH

Subjects

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Figure 3.3a

Boxplots: Frication in "botch it"

Duration in seconds

JL  CK  AH  LH

Subjects

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2. Tests of Significance

2.1 Method of Analysis

See Experiment 1. The three hypotheses tested in Experiment 2 will be analyzed separately.

2.2 Analysis of Results

2.2.1. Hypothesis 1: Comparison of Clusters and Affricates

The first hypothesis tested was that durations of inter-word stop + fricative clusters behave differently than word-initial affricates. Although it is known that clusters and affricates have different durational properties, to my knowledge, implementation of these phonetic regularities in connected speech has received little attention in the literature. Testing this hypothesis would verify that speakers, in connected speech, distinguish between clusters and affricates, and would specifically point to those components (preceding vowel, closure or frication) which offer contrastive acoustic cues to this distinction.

Review of mean durations presented in Table 3.9 (test words = "bought ships" and "gnaw chips") and median durations (Figures 3.10, 3.10a, 3.11, 3.11a, 3.12 and 3.12a) suggest that (1.) durations of vowels preceding
interword stop + fricative clusters are shorter than vowels preceding word initial affricates, (2.) closure portions of these clusters are shorter than those of word initial affricates, but (3.) fricatives are longer than the frication portions of the affricates.

Table 3.9

Experiment 2: Moments of Utterances "bought ships" and "gnaw chips" in Seconds

Moments of Utterance "bought ships" in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>5</td>
<td>.133294</td>
<td>.000146</td>
<td>.067887</td>
</tr>
<tr>
<td>CK</td>
<td>5</td>
<td>.109072</td>
<td>.000029</td>
<td>.030353</td>
</tr>
<tr>
<td>AH</td>
<td>5</td>
<td>.115695</td>
<td>.000093</td>
<td>.058678</td>
</tr>
<tr>
<td>FP</td>
<td>5</td>
<td>.101043</td>
<td>.000250</td>
<td>.045100</td>
</tr>
<tr>
<td>SM</td>
<td>5</td>
<td>.131753</td>
<td>.000391</td>
<td>.066717</td>
</tr>
<tr>
<td>SE</td>
<td>5</td>
<td>.126853</td>
<td>.000137</td>
<td>.046872</td>
</tr>
</tbody>
</table>

Moments of Utterance "gnaw chips" in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Vowel</th>
<th>Closure</th>
<th>Frication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Variance</td>
<td>Mean</td>
</tr>
<tr>
<td>JL</td>
<td>5</td>
<td>.169213</td>
<td>.000098</td>
<td>.071185</td>
</tr>
<tr>
<td>CK</td>
<td>5</td>
<td>.128815</td>
<td>.000861</td>
<td>.037598</td>
</tr>
<tr>
<td>AH</td>
<td>5</td>
<td>.161351</td>
<td>.000635</td>
<td>.070201*</td>
</tr>
<tr>
<td>FP</td>
<td>5</td>
<td>.129554</td>
<td>.000228</td>
<td>.054293</td>
</tr>
<tr>
<td>SM</td>
<td>5</td>
<td>.171623</td>
<td>.000833</td>
<td>.080934</td>
</tr>
<tr>
<td>SE</td>
<td>5</td>
<td>.108536</td>
<td>.000195</td>
<td>.067256</td>
</tr>
</tbody>
</table>

*N = 4
Figure 3.10

Boxplots: Vowel Duration in "gnaw chips"

Subjects

JL  CK  AH  FP  SM  SE
Figure 3.10a

Boxplots: Vowel Duration in "bought ships"
Figure 3.11a

Boxplots: Closure Duration in "bought ships"
Figure 3.12

Boxplots: Frication duration in "gnaw chips"
Figure 3.12a

Boxplots: Frication Duration in "bought ships"
p values for the results of directional t-tests are presented in Table 3.10. They show that for most of the speakers the vowel and frication duration effects are quite strong, while the closure duration effect is weak.

Table 3.10

Experiment 2: p Values for Directional t-Tests of Durations of Inter-word Stop + Plosive Clusters and Word-initial Affricates

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p(Vowel)</th>
<th>p(Closure)</th>
<th>p(Frication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.001</td>
<td>0.4</td>
<td>0.001</td>
</tr>
<tr>
<td>CK</td>
<td>0.1</td>
<td>0.05</td>
<td>0.025</td>
</tr>
<tr>
<td>AH</td>
<td>0.005</td>
<td>0.25</td>
<td>anomalous</td>
</tr>
<tr>
<td>FP</td>
<td>0.01</td>
<td>0.25</td>
<td>0.001</td>
</tr>
<tr>
<td>SM</td>
<td>0.025</td>
<td>0.25</td>
<td>0.001</td>
</tr>
<tr>
<td>SE</td>
<td>anomalous</td>
<td>0.05</td>
<td>0.001</td>
</tr>
</tbody>
</table>

2.2.2. Hypothesis 2: Comparison of Word-Initial and Word-Final Affricates

The second hypothesis tested was that duration of word-initial affricates would differ from word-final affricates: that location of the segment vis-a-vis the word boundary would affect its duration.

Here I was able to collect complete data sets for three subjects. Review of mean durations in Table 3.8 (test words = "botch it") and Table 3.9 (test words = "gnaw chips") suggests the following effects: (1.) vowels
preceding word-final affricates are shorter than those preceding word boundaries; (2.) closure durations of word-final affricates are shorter than those in word-initial position, but (3.) frication portions of word-final affricates are longer than their word-initial counterparts.

p values of one directional t-tests are presented in Table 3.11.

These effects proved to be significant for the majority of speakers.

Table 3.11

Experiment 2: p Values for Directional t-Tests of Durations of Word-final and Word-initial Affricates

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p(Vowel)</th>
<th>p(Closure)</th>
<th>p(Frication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.001</td>
<td>0.001</td>
<td>0.25</td>
</tr>
<tr>
<td>CK</td>
<td>0.1</td>
<td>0.05</td>
<td>0.001</td>
</tr>
<tr>
<td>AH</td>
<td>0.001</td>
<td>0.005</td>
<td>0.025</td>
</tr>
</tbody>
</table>
2.2.3. **Hypothesis 3: Comparison of Palatalized Sequences and Affricates**

The third hypothesis tested was that the durations of affricates with underlying stop + glide representation (palatalized sequences) would differ from those which are underlingly affricates (in word-initial, -final or -medial position).

**Hypothesis 3.1: Comparison with Word-Medial Affricates**

I first compared the duration of palatalized sequences with those of word medial affricates. If there were no differences between the two, then palatalized sequences would not show special sensitivity to word boundary information. Review of the mean durations presented in Table 3.7 (test words "digits" and "did you") suggested the following: (1.) duration of vowels preceding palatalized sequences were longer than those preceding word-medial affricates; (2) closure durations of the former were longer, and (3.) frication portions were longer.

*p* values of directional t-tests are presented in Table 3.12. They show a very large degree of individual variation: for half the speakers the vowel effect is strong, for the other half it is weak. For half the speakers the frication effect is strong, but for the other half it is quite weak. The only effect that is strong for most of the speakers is that closure durations of
palatalized sequences are longer than those of word-medial affricates. This result for affricates concurs with findings by Zue (1985) and Umeda (1977) that closure portions of /t/ word-medial allophones were shorter than allophones at word boundaries.

Table 3.12

Experiment 2: p Values for Directional t-Tests of Durations of Word-medial Affricates and Inter-word Palatalized Sequences

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p(Vowel)</th>
<th>p(Closure)</th>
<th>p(Frication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.005</td>
<td>0.001</td>
<td>0.01</td>
</tr>
<tr>
<td>CK</td>
<td>0.25</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>AH</td>
<td>anomalous</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>DE</td>
<td>0.4</td>
<td>0.001</td>
<td>0.4</td>
</tr>
<tr>
<td>FP</td>
<td>0.025</td>
<td>0.025</td>
<td>0.4</td>
</tr>
<tr>
<td>WT</td>
<td>0.05</td>
<td>0.25</td>
<td>0.001</td>
</tr>
<tr>
<td>SM</td>
<td>0.01</td>
<td>0.001</td>
<td>0.25</td>
</tr>
<tr>
<td>LH</td>
<td>0.25</td>
<td>0.4</td>
<td>0.001</td>
</tr>
</tbody>
</table>

This suggests that durations of palatalized sequences show temporal variation in relation to word boundary information. The next question to be asked is whether their temporal properties are more like those of word-initial, or of word-final, affricates, or whether they are like neither of them.
Hypothesis 3.2 Comparison with Word-Final Affricates

The second hypothesis tested was whether the durational properties of palatalized sequences were similar to those of word-final affricates. Review of the mean durations presented in Table 3.8 (test words "botch it" and "bought you") suggest (1.) vowels preceding palatalized sequences were shorter than those preceding word-final affricates; (2.) closure durations of palatalized sequences were longer than those of word-final affricates, and (3.) frication portions of palatalized sequences were longer than their word-final affricate counterparts.

p values are presented in Table 3.13. The vowel effect is shown to be negligible for 3 out of 4 speakers. The closure duration effect shows considerable inter-speaker variation, and for 3 out of 4 speakers the frication duration effect is weak.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p(Vowel)</th>
<th>p(Closure)</th>
<th>p(Frication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.025</td>
<td>0.025</td>
<td>0.1</td>
</tr>
<tr>
<td>CK</td>
<td>0.4</td>
<td>0.025</td>
<td>0.01</td>
</tr>
<tr>
<td>AH</td>
<td>0.25</td>
<td>0.1</td>
<td>0.4</td>
</tr>
<tr>
<td>LH</td>
<td>0.25</td>
<td>anomalous</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Table 3.13

Experiment 2: p Values for Directional t-Tests of Durations of Palatalized Sequences and Word-final Affricates
Hypothesis 3.3 Comparison with Word-Initial Affricates

Review of mean durations of test words "bought you" in Table 3.8 and and "gnaw chips" in Table 3.9 suggests three effects: (1.) vowels preceding palatalized sequences are shorter than those preceding word-initial affricates; (2.) closure duration of palatalized sequences are shorter than those of word-initial affricates, and (3.) frication duration of palatalized sequences are shorter than those of word-initial affricates.

p values are presented in Table 3.14. They indicate that the vowel effect is quite strong for all three speakers, the closure effect is very strong for two out of three speakers, and the frication duration effect is strong for two out of three speakers.

Table 3.14

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p(Vowel)</th>
<th>p(Closure)</th>
<th>p(Frication)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.001</td>
<td>0.001</td>
<td>anomalous</td>
</tr>
<tr>
<td>CK</td>
<td>0.025</td>
<td>anomalous</td>
<td>0.005</td>
</tr>
<tr>
<td>AH</td>
<td>0.001</td>
<td>0.001</td>
<td>0.005</td>
</tr>
</tbody>
</table>

Discussion

Hypothesis 1: Comparison of clusters and affricates

Inter-word stop + fricative cluster durations differ significantly from word-initial affricate durations in two
ways: (1) for most speakers, vowel durations preceding word-initial affricates are longer than those preceding inter-word stop + fricative clusters because they are in open syllables; and (2) for most speakers, the durations of the frication portion of word initial affricates are shorter than the fricatives in stop + fricative clusters.

**Hypothesis 2: Comparison of word-initial and word-final affricates**

The vowel duration effect is predictable, as vowels preceding word-final affricates are in closed syllables, and therefore shorter than vowels in open syllables. However, only 2 out of 3 speakers show this effect, which is reflective of the suggestion by Crystal and House (1982) that certain effects present in "laboratory speech" may be diminished or neutralized in connected speech. However, the results do show that the consonantal portion examined does show sensitivity to word boundary information. It is interesting to note, however, that the frication portions of word-final affricates are longer than their word-initial counterparts, while Klatt (1974) found the converse to be true for fricative durations.

**Hypothesis 3: Comparison of palatalized sequences and affricates**

Speakers do not seem to systematically differentiate palatalized sequences and word-final affricates along a temporal dimension.
The vowel duration effect shown here is in agreement with that shown in Hypothesis 3.1, namely that vowels preceding word-initial affricates are longer than those preceding word-final affricates. The results in Hypothesis 3.1 also showed frication portions of word-initial affricates to be shorter than their word-final counterparts. Results of Hypothesis 3.3 show that for the majority of speakers the frication portion of word-initial affricates are longer than those of palatalized sequences.

General Conclusions

The results of testing all three hypotheses seem to indicate that although the duration of the vowel preceding palatalized sequences suggests it is produced as a word-final affricate, the consonantal portion, specifically the frication duration, shows a temporal dimension in which the duration of the palatalized sequence is implemented neither as a word-final affricate nor as a word-initial affricate, but as something in between. These results suggest that although palatalization of stops by glides is discontinuous in the sense that assimilation is complete, it also shows a continuous temporal component that has not been accounted for in consideration of its operation as a sandhi rule.
EXPERIMENT 3

Introduction

Experiment 3 tests the claim that palatalization of fricatives can best be understood as a phonetic, continuous rule. Specifically, I formulated two hypotheses: one spectral, the other durational.

1. Spectral Hypothesis

Zue and Shattuck-Hufnagel (1980) found assimilation of fricatives to be complete and discontinuous, that is, no residue of the underlying place of articulation was present in the palatalized fricative. In this experiment I tested the hypothesis that these results would be replicated by examining formant transitions into the fricative. Replication of these results would also indicate that palatalization of fricatives is a discontinuous effect in connected speech, as well as in the "laboratory" speech already examined in Zue and Shattuck-Hufnagel's study.

Hypothesis 1 tested whether transition endpoints preceding anticipatorily palatalized fricatives were the same as those preceding geminate palato-alveolar fricatives. My second, corollary, hypothesis (Hypothesis 1.2) was that transitions into palatalized fricatives with different underlying representations (one anticipatory palatalization, the other perseverative) would be identical. Together, these hypotheses claim that palatalization of fricatives is a discontinuous rule
insofar as place of articulation is concerned.

2. Durational Hypothesis

Three specific sub-hypotheses were tested. Together, they test whether there is a durational component to inter-word palatalization of fricatives. Hypothesis 2.1 tested whether the durations of geminate palato-alveolar fricatives can be distinguished on the basis of their underlying phonemes. Specifically, I hypothesized that geminate fricatives resulting from anticipatory palatalization are not identical to those that do not have an underlying palatalized representation.

Hypothesis 2.2 tested whether palato-alveolar fricatives resulting from perseverative palatalization triggered by different phonemes have similar durational properties even though their respective underlying representations differ. Thus, under the first hypothesis, fricatives with different underlying representations have different surface forms. In the second hypothesis, fricatives with different underlying forms have similar surface representations.

Hypothesis 2.3 concerns palatalization of affricates, and claims that, even when in a cluster, affricates resulting from palatalization are significantly different from their surface counterparts that did not result from palatalization.
Methods

1. Speakers

See Experiments 1 and 2.

2. Data Corpus

2.1 Test Words and Control Words

As in the previous two experiments, the corpus was divided between control and test utterances. Control utterances contained test words with geminate [ʃ], e.g. "josh Sheila", and geminate [s], e.g. "boss seems", to act as bases of comparison for spectral assimilation and, in the case of the former, as a durational example of gemination.

The five test utterances were as follows: (1.) [s] + [ʃ] clusters, (2.) [ʃ] + [st] clusters, (3.) [s] + [ʃ] clusters, (4.) [ʃ] + [st] clusters and (5.) [s] + [ʃ] clusters. In test utterances 1, 3 and 5, assimilation would optionally apply in an anticipatory direction; in test utterances 2 and 4 in a perseverative direction.

2.2 Segmental and Syllabic Controls

All test words had the same vowel, [ə], preceding the fricative clusters, and [I] following. An effort was made to maintain a similar syllable count in all utterances. Test words were preceded by 1-3 syllables and followed by 3-4 syllables in each utterance.

Stress was not considered to be a factor in palatalization of fricatives (see above), thus the test...
words did not consist of stressed + unstressed syllables. In four test utterances, however, subjects were instructed to place emphatic stress on the first or second syllable of the utterance. De-emphasizing the test words, I felt, would increase the likelihood of subjects applying the optional palatalization rule.

2.3 Utterances

The utterances were as follows (test words underlined and word receiving emphatic stress in capitals):

CONTROL

(1.) He'll josh Sheila about this afternoon.
(2.) His boss seems to understand.

TEST

(1.) I SAW them toss sheepskins into the truck.
(2.) This is MY squash steamer, not yours.
(3.) HE wouldn't toss you out of here.
(4.) I LOVE to watch steel glisten in the sun.
(5.) Carefully, toss cheese into the pasta.

2.4 Presentation of Corpus to Speakers

The corpus consisted of 5 repetitions each of the control sentences and 10 repetitions of each test sentence. They were presented to subjects in pseudo-random order in two blocks. The first block began and ended with a filler utterance, and the second block began with a filler sentence and ended with two fillers. Order of presentation
of blocks was reversed for half the subjects.

3. Experimental Procedure

3.1 Recording

Data were collected from six of the speakers who participated in Experiment 1. Five of the speakers returned for a second recording session during which utterances for Experiments 2 and 3 were recorded. Subject SE was the only speaker who did not also participate in Experiment 1.

3.2 Equipment

See Experiment 1.

3.3 Transcription

See Experiment 1. The following parts of the test words were marked: vowel onset and vowel offset were marked by onset and offset of periodic voicing, in conjunction with LPC second and third formant traces (see 3.3 Transcription, Experiment 1 above.) Fricative boundaries were marked according to onset and offset of aperiodic frication in conjunction with the spectrographic display. Stop closure was marked when relevant, and the following vowel was marked as well.

Many speakers exhibited an epenthetic silence between vowel and fricative (especially between the fricative and the vowel following it). These silences were marked with the symbol "§". Although I realized that by not including
these epenthetic silences in the spectral analysis I risked losing transition information, I felt that marking them as such was absolutely necessary to obtaining reliable durational measurements.

3.3.1. Temporal Markers

See Experiment 2.

3.4 Analysis of Spectral Information

See Experiment 1.

Results

1. Spectral Hypotheses

1.1 Hypothesis 1 - Comparison of Palatalized and Geminate Sequences

1.1.1 Descriptive Statistics

First order statistics of F2 and F3 transition endpoints preceding anticipatorily palatalized fricatives (in the test words "toss sheepskins") and geminate palato-alveolar fricatives (in the test words "josh Sheila") are presented in Tables 3.15 and 3.16 respectively. The extremely large standard deviation in F2 and F3 endpoints into geminate fricatives in Table 3.16 for speaker AH appears to be an artifact or error. For this reason, his data were not included in the analysis.

First order statistics of F2 and F3 transition endpoints preceding geminate alveolar fricatives (test words "boss seems") are presented in Table 3.17.
Table 3.15

Experiment 3: Formant Endpoints (in Hz) of Test Utterance
"toss sheepskins" (Palatalized)

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL F2</td>
<td>10</td>
<td>1577.56</td>
<td>219.91</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2466.22</td>
<td>78.85</td>
</tr>
<tr>
<td>CK F2</td>
<td>10</td>
<td>1463.20</td>
<td>99.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2380.80</td>
<td>80.60</td>
</tr>
<tr>
<td>AH F2</td>
<td>10</td>
<td>1333.00</td>
<td>107.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2514.10</td>
<td>62.69</td>
</tr>
<tr>
<td>FP F2</td>
<td>10</td>
<td>1587.89</td>
<td>74.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2424.89</td>
<td>89.82</td>
</tr>
<tr>
<td>SM F2</td>
<td>10</td>
<td>1377.29</td>
<td>105.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2453.43</td>
<td>60.73</td>
</tr>
<tr>
<td>SE F2</td>
<td>8</td>
<td>1443.71</td>
<td>110.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2627.25</td>
<td>55.35</td>
</tr>
</tbody>
</table>
Table 3.16

Experiment 3: Formant Endpoints (in Hz) of Control Utterance "josh Sheila"

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL F2</td>
<td>5</td>
<td>1619.75</td>
<td>50.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2387.00</td>
<td>53.69</td>
</tr>
<tr>
<td>CK F2</td>
<td>5</td>
<td>1519.00</td>
<td>43.84</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2418.00</td>
<td>55.45</td>
</tr>
<tr>
<td>AH F2</td>
<td>5</td>
<td>2039.80</td>
<td>831.45</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2938.80</td>
<td>1027.85</td>
</tr>
<tr>
<td>FP F2</td>
<td>5</td>
<td>1464.75</td>
<td>101.34</td>
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<tr>
<td></td>
<td></td>
<td>2348.25</td>
<td>40.27</td>
</tr>
<tr>
<td>SM F2</td>
<td>5</td>
<td>1500.40</td>
<td>69.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2461.40</td>
<td>50.37</td>
</tr>
<tr>
<td>SE F2</td>
<td>5</td>
<td>1426.00</td>
<td>73.36</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2721.80</td>
<td>49.60</td>
</tr>
<tr>
<td>Spkr</td>
<td>N</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>------</td>
<td>---</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>JL F2</td>
<td>5</td>
<td>1356.25</td>
<td>134.01</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2433.50</td>
<td>55.89</td>
</tr>
<tr>
<td>CK F2</td>
<td>5</td>
<td>1258.60</td>
<td>88.99</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2430.40</td>
<td>54.06</td>
</tr>
<tr>
<td>AH F2</td>
<td>5</td>
<td>1395.00</td>
<td>65.03</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2610.20</td>
<td>12.41</td>
</tr>
<tr>
<td>FP F2</td>
<td>5</td>
<td>1202.80</td>
<td>124.62</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2529.60</td>
<td>66.77</td>
</tr>
<tr>
<td>SM F2</td>
<td>5</td>
<td>1302.00</td>
<td>110.33</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2650.50</td>
<td>46.50</td>
</tr>
<tr>
<td>SE F2</td>
<td>5</td>
<td>1202.80</td>
<td>53.33</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2628.80</td>
<td>36.15</td>
</tr>
</tbody>
</table>
1.1.2. Tests of Significance

1.1.2.1. Method of Analysis

See Experiment 1. Hypotheses will be tested separately.

1.1.2.2. Analysis of Results

Paired non-directional t tests were performed on the mean F2 endpoints in Tables 3.15 and 3.16, and the resulting p-values presented in Table 3.18.

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.8</td>
</tr>
<tr>
<td>CK</td>
<td>0.1</td>
</tr>
<tr>
<td>FP</td>
<td>0.02</td>
</tr>
<tr>
<td>SM</td>
<td>0.05</td>
</tr>
<tr>
<td>SE</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 3.18

Experiment 3: p Values for Non-Directional t-Tests of Mean F2 Endpoints Preceding Geminate Palato-alveolar Fricatives and Palatalized Fricatives

The p values show a fair degree of inter-speaker variation: for two of the speakers, FP and SM, the means show a strongly significant difference, while for the other three speakers, the difference is very weak.

Review of the data presented in Table 3.17 suggested mean endpoints of F2 preceding palatalized sequences to be significantly higher than those preceding alveolar
fricatives. A one-directional t-test showed this to be the case for most speakers (see p values in Table 3.19).

Table 3.19

Experiment 3: p Values for Directional t-Tests of Mean F2 Endpoints Preceding Geminate Alveolar Fricatives and Palatalized Fricatives

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.05</td>
</tr>
<tr>
<td>CK</td>
<td>0.001</td>
</tr>
<tr>
<td>AH</td>
<td>anomalous</td>
</tr>
<tr>
<td>FP</td>
<td>0.001</td>
</tr>
<tr>
<td>SM</td>
<td>0.25</td>
</tr>
<tr>
<td>SE</td>
<td>0.001</td>
</tr>
</tbody>
</table>

1.2. Hypothesis 2 - Comparison of F2 Endpoints Preceding Anticipatorily Palatalized Sequences vs. Perseveratively Palatalized Sequences

1.2.1. Descriptive Statistics

First order statistics of the F2 and F3 endpoints of transitions into anticipatorily palatalized fricatives (test words "toss sheepskins") and perseveratively palatalized fricatives (test words "squash steamer") are presented in Table 3.15 and 3.20 respectively.
Table 3.20

Experiment 3: Formant Endpoints (in Hz) of Test Utterance
"squash steamer" (Palatalized)

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL F2</td>
<td>10</td>
<td>1625.78</td>
<td>65.53</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2232.00</td>
<td>112.84</td>
</tr>
<tr>
<td>CK F2</td>
<td>10</td>
<td>1539.67</td>
<td>35.80</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2366.33</td>
<td>70.84</td>
</tr>
<tr>
<td>AH F2</td>
<td>9</td>
<td>1636.11</td>
<td>122.07</td>
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<tr>
<td>F3</td>
<td></td>
<td>2387.00</td>
<td>52.69</td>
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<tr>
<td>FP F2</td>
<td>10</td>
<td>1481.80</td>
<td>171.93</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2309.50</td>
<td>59.23</td>
</tr>
<tr>
<td>SM F2</td>
<td>10</td>
<td>1445.38</td>
<td>187.89</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2359.44</td>
<td>34.11</td>
</tr>
<tr>
<td>SE F2</td>
<td>7</td>
<td>1386.14</td>
<td>67.74</td>
</tr>
<tr>
<td>F3</td>
<td></td>
<td>2433.14</td>
<td>69.74</td>
</tr>
</tbody>
</table>

1.2.2. Tests of Significance

p values for paired non-directional t-tests are presented in Table 3.21. For the majority of speakers the mean F2 endpoints do not differ significantly.

It is interesting to note that the standard deviations of either one mean or the other for speakers JL, FP and SM are over 150 Hz (see Table 3.20). Consequently, the results for these three speakers may not be particularly reliable. The results for speakers CK and AH show second
formant endpoints to be significantly different for the two means, while only for speaker SE are they the same.

Table 3.21

Experiment 3: p Values for Non-Directional t-Tests of Mean F2 Endpoints Preceding Anticipatorily Palatalized Fricatives and Perseveratively Palatalized Fricatives

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.8</td>
</tr>
<tr>
<td>CK</td>
<td>0.05</td>
</tr>
<tr>
<td>AH</td>
<td>0.002</td>
</tr>
<tr>
<td>FP</td>
<td>0.1</td>
</tr>
<tr>
<td>SM</td>
<td>0.5</td>
</tr>
<tr>
<td>SE</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Discussion - Spectral Hypotheses

The results of these tests show (1.) that F2 endpoints preceding palatalized sequences are higher than those preceding geminate alveolar fricatives, (2.) that for the majority of speakers they do not differ significantly from F2 endpoints preceding geminate palato-alveolar fricatives, and (3.) that the direction of assimilation does not affect the degree of palatalization represented in the F2 endpoints. They support the findings presented in Zue and Shattuck-Hufnagel (1980) that palatalization is a discontinuous, rather than a continuous, effect.
2. Durational Hypotheses

2.1. Hypothesis 1 - Comparison of Durations of Palatalized Fricatives and Geminate Fricatives

2.1.1. Descriptive Statistics

Table 3.22 presents first order statistics of control utterance (1.) (test words "josh Sheila") and test utterance (1.) (test words "toss sheepskins"). Boxplots of the distribution of durations for these two utterances for all speakers are presented in Figures 3.13 and 3.14.

Table 3.22

Experiment 3: Moments of Control Utterance "josh Sheila" and Test Utterance "toss sheepskins" (Palatalized) in Seconds

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>5</td>
<td>.157716</td>
<td>.000122</td>
<td>10</td>
<td>.133272</td>
<td>.000466</td>
</tr>
<tr>
<td>CK</td>
<td>5</td>
<td>.178575</td>
<td>.000113</td>
<td>10</td>
<td>.141665</td>
<td>.000401</td>
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<td>5</td>
<td>.122577</td>
<td>.003322</td>
<td>10</td>
<td>.109725</td>
<td>.000543</td>
</tr>
<tr>
<td>FP</td>
<td>5</td>
<td>.138588</td>
<td>.000095</td>
<td>10</td>
<td>.119408</td>
<td>.000207</td>
</tr>
<tr>
<td>SM</td>
<td>5</td>
<td>.177429</td>
<td>.000590</td>
<td>10</td>
<td>.148216</td>
<td>.000470</td>
</tr>
<tr>
<td>SE</td>
<td>5</td>
<td>.149628</td>
<td>.000082</td>
<td>8</td>
<td>.134866</td>
<td>.000394</td>
</tr>
</tbody>
</table>
Figure 3.13

Boxplots: frication duration in "josh Sheila"

Duration in seconds

Subjects

JL  CK  AH  FP  SM  SE
Figure 3.14

Boxplots: Fricative Duration in "toss sheepkins"

Subjects: JL, CK, AH, FP, SM, SE

Duration in seconds: 0.06, 0.08, 0.1, 0.12, 0.14, 0.16, 0.18, 0.2
2.1.2. Tests of Significance

Review of the mean durations in Table 3.22 suggests durations of palatalized sequences to be shorter than those of geminate palato-alveolar fricatives. This was tested by means of paired one-directional t-tests. p values are presented in Table 3.23.

Table 3.23

Experiment 3: p Values for Directional t-Tests of Mean Durations of Palatalized Fricatives and Geminate Fricatives

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.025</td>
</tr>
<tr>
<td>CK</td>
<td>0.005</td>
</tr>
<tr>
<td>AH</td>
<td>0.4</td>
</tr>
<tr>
<td>FP</td>
<td>0.01</td>
</tr>
<tr>
<td>SM</td>
<td>0.025</td>
</tr>
<tr>
<td>SE</td>
<td>0.1</td>
</tr>
</tbody>
</table>

For most of the speakers, the durational effect is strong, indicating that palatalized fricatives have a significantly shorter duration than their geminate counterparts.

2.2 Hypothesis 2 - Comparison of Durations of Anticipatorily vs. Perseveratively Palatalized Fricatives

2.2.1. Descriptive Statistics

First order statistics for fricatives in test
utterances (2.) (test words "squash steamer") and (3.)
test words "toss you") are presented in Table 3.24.
Figures 3.15 and 3.16 show boxplots for these data. It is
a well known fact that durations of fricative + stop
clusters are shorter than fricative + fricative clusters,
and this is reflected in mean durations of test words
"squash steamer" and "josh Sheila" in Tables 3.24 and 3.22
respectively. However, anticipatory palatalization
involving fricative + glide sequences may include an
optional yod, and the duration of the resulting fricative
may be more comparable to that in a perseveratively
palatalized cluster.

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>10</td>
<td>.088260</td>
<td>.000115</td>
<td>10</td>
<td>.099635</td>
<td>.000038</td>
</tr>
<tr>
<td>CK</td>
<td>10</td>
<td>.110362</td>
<td>.000063</td>
<td>3</td>
<td>.117900</td>
<td>.000098</td>
</tr>
<tr>
<td>AH</td>
<td>9</td>
<td>.087044</td>
<td>.000323</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FP</td>
<td>10</td>
<td>.097151</td>
<td>.000148</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>10</td>
<td>.096334</td>
<td>.000104</td>
<td>7</td>
<td>.099759</td>
<td>.000153</td>
</tr>
<tr>
<td>SE</td>
<td>7</td>
<td>.098492</td>
<td>.000020</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 3.15

Boxplots: Duration of Fricative in "squash steamer"
Figure 3.16

Boxplots: $\lfloor \right \rfloor$ duration in "toss you"

Duration in seconds

Subjects

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Only half the subjects applied the palatalization rule to \([s] + [j]\) clusters. Of those three, one applied in all ten repetitions, one in the majority of repetitions, and the third in only three repetitions. Thus the results for Hypothesis 2 are more constrained than those for the other two hypotheses tested.

2.2.2. Tests of Significance

Review of the results in Table 3.24 show mean durations of perseveratively palatalized fricatives to be shorter than those of anticipatorily palatalized fricatives. The strength of this effect was tested by means of a one-directional t-test, p-values for which are presented in Table 3.25. This effect is strong for one speaker, but weak for two. It seems, then, that for the majority of speakers, perseveratively palatalized fricatives are not significantly shorter than those which also involve a consonantal cluster and are palatalized anticipatorily.

Table 3.25

<table>
<thead>
<tr>
<th>Speaker</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.005</td>
</tr>
<tr>
<td>CK</td>
<td>0.1</td>
</tr>
<tr>
<td>SM</td>
<td>0.4</td>
</tr>
</tbody>
</table>
2.3 Hypothesis 3 - Comparison of Durations of Palatalized Affricates and Non-Palatalized Affricates

2.3.1. Descriptive Statistics

First order statistics of the frication portion of the surface affricate resulting from perseverative palatalization of \([s]\) by \([\mathring{f}]\) (test utterance 4.) (test words "watch steel") and of the palato-alveolar affricate with no underlying phoneme (test utterance 3.b from Experiment 2: test words "botch it") are presented in Table 3.26.

Table 3.26

<table>
<thead>
<tr>
<th>Spkr</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
<th>N</th>
<th>Mean</th>
<th>Variance</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>9</td>
<td>0.101278</td>
<td>0.000103</td>
<td>5</td>
<td>0.075638</td>
<td>0.000243</td>
</tr>
<tr>
<td>CK</td>
<td>10</td>
<td>0.093978</td>
<td>0.000115</td>
<td>5</td>
<td>0.081448</td>
<td>0.000004</td>
</tr>
<tr>
<td>AH</td>
<td>1</td>
<td>0.110936</td>
<td>n/a</td>
<td>5</td>
<td>0.064955</td>
<td>0.000321</td>
</tr>
<tr>
<td>LH</td>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>0.053584</td>
<td>0.000066</td>
</tr>
<tr>
<td>FP</td>
<td>9</td>
<td>0.098557</td>
<td>0.000131</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM</td>
<td>9</td>
<td>0.122635</td>
<td>0.001262</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>2</td>
<td>0.119102</td>
<td>0.000269</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Boxplots of their distribution are presented in Figures 3.17 and 3.9 (see above).
Figure 3.17

Boxplots: [\text{Duration in "watch steel"}]

Subjects

JL  CK  FP  SM
2.3.2. Tests of Significance

Data from speakers AH and SE were not included in the analysis because they had insufficient tokens of palatalized fricatives. Interestingly, the majority of repetitions for both speakers exhibited anticipatory assimilation.

Review of the mean durations of the frication portions presented in Table 3.26 show that for speakers JL, FP and SM, durations of palatalized affricates are significantly longer than those of singleton affricates, while for speaker CK they are shorter. p values of paired one directional t-tests show all these effects to be highly significant (see Table 3.27).

Table 3.27

Experiment 3: p Values for Directional t-Tests of Durations of Palatalized Sequences and Singleton Affricates

<table>
<thead>
<tr>
<th>Speaker</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>JL</td>
<td>0.005</td>
</tr>
<tr>
<td>CK</td>
<td>anomalous*</td>
</tr>
<tr>
<td>FP</td>
<td>0.001</td>
</tr>
<tr>
<td>SM</td>
<td>0.005</td>
</tr>
</tbody>
</table>

* 0.005 in opposite direction

Discussion - Durational Hypotheses

The first durational hypothesis tested the temporal component of palatalization of fricatives by indicating
that palatalized fricatives are not the same length as geminates, but rather are shorter. This suggests that although palatalization of fricatives may be considered a discontinuous rule in regard to place of articulation, there is evidence of a durational, continuous component as well. Furthermore, results from testing Hypothesis 2 suggest that direction of palatalization does not significantly affect the durational representation of the palatalized segment.

Results from testing Hypothesis 3 suggest that the duration of fricatives palatalized by affricates operates in a parallel fashion: as there are no geminate affricates in English, the resulting affricate is different than its surface counterpart by being significantly longer than a singleton affricate.
Chapter 4

Durations of Palatalized Allophones are Postlexical

4.1 Segment Duration is Postlexical

The results of the experiments described in Chapter 3 show that durational patterns of palatalized sequences are not like anything found in word-initial or word-final segments. As the durations of stops and fricatives that have been palatalized are not the same as durations of the segments specified in the lexicon, they are therefore postlexical.

As discussed in Chapter 2, there is an unresolved controversy as to the nature of postlexical rules. Kiparsky (1985) suggested that a single rule could be discontinuous when applied lexically, but continuous when applied postlexically. Unfortunately, there are few examples of how this might occur in English. Liberman (1983) claims that postlexical, or phonetic, rules have a temporal component, but he too does not offer examples from English.

The results of my experiments show how English postlexical palatalization is both discontinuous and continuous. It is discontinuous in that it is a feature-changing rule: assimilation of place of articulation is complete. It is also continuous in that the palatalized allophones differ temporally from their non-palatalized counterparts.
4.2 Asymmetries in Phonological Patterning

In addition to examining the fine phonetic details of inter-word palatalization, I also looked at its phonological patterns, and found a number of asymmetries between palatalization by glides and by fricatives that have been ignored in the literature. These asymmetries provide further support that postlexical palatalization has both a discontinuous and a continuous, temporal, component.

Palatalization of obstruents is described (e.g. Halle and Mohanan, 1985) as a single phonological rule:

\[ [+ \text{alv}] \rightarrow [+ \text{pal}] / \text{___}[+ \text{pal}] \]

Inter-word palatalization can be triggered by either a palatal glide \([j]\) (e.g. Cooper et al., 1978, 1984) or a palato-alveolar fricative \([ʃ]\) (e.g. Shattuck-Hufnagel et al. 1978, Zue and Shattuck-Hufnagel, 1980). I am not aware of any studies involving palatalization triggered by palato-alveolar affricates.

Although collapsed as a single rule, inter-word palatalization exhibits four interesting asymmetries in phonological patterns.

1) Asymmetry in presence of voicing assimilation

The manner of articulation of the palatalizing segment constrains the presence of voicing assimilation. If the segment palatalized by a glide is voiceless, the resulting affricate or fricative is voiceless, e.g. "hit
you" $\rightarrow$ [hɪ ʃ(j)u], instead of *[hɪ ʒ(j)u]; "miss you" $\rightarrow$ [mɪʃ(j)u], instead of *[mɪʒ(j)u]. However, yod deletion is optional, and if it is not deleted, then there is no voicing assimilation.

When palatalization is triggered by fricatives, the result is anticipatory voicing assimilation: "his shoes" $\rightarrow$ [hɪʃuːz], and not *[hɪʒuːz]. It should be noted that this voicing assimilation could also be interpreted as haplogy.

2) Asymmetry in direction of place assimilation
The identity of the palatalizing segment also controls the direction of assimilation. Palatalization by glides results solely in anticipatory assimilation, e.g. "aid you" $\rightarrow$ [eɪd ʃ(j)u], but "pay tomorrow" $\rightarrow$ *[pɛ̃d ʒəməro]. Similarly "lace your" $\rightarrow$ [liʃ(j)ə], but "pay something" $\rightarrow$ *[pɛ̃ʃəməɾj]. However, when palatalization is triggered by fricatives, the direction of assimilation is anticipatory, e.g. "gas shortage" $\rightarrow$ [ɡæʃərəz], but can also be perseverative if the palatalized fricative is part of a fricative-stop cluster, as in "fresh strawberries" $\rightarrow$ [frestərəbərəz]. It should be noted here that the latter assimilation can also be interpreted as an instance of haplogy. As it is not possible to provide conclusive evidence for one description or the other, I will assume here that it is indeed an example of perseverative assimilation, with the caveat that it can be otherwise interpreted.
3) Asymmetry in sensitivity to segmental conditioning factors

Identity of adjacent segments does not seem to affect the occurrence of palatalization triggered by glides. That is, palatalization is not blocked if the first word at the palatalization site ends in a cluster, such as "I'll cast your possessions home" \(\rightarrow [\text{kar} \text{yl(j)} \text{x}]\). However, the identity of adjacent segments does affect palatalization triggered by fricatives, in that it constrains the direction of assimilation: perseverative palatalization can occur only if the alveolar fricative is part of a cluster (see above).

4) Asymmetry in sensitivity to suprasegmental conditioning factors

Prosodic factors, in particular stress, have been noted in the literature to control occurrence of palatalization triggered by glides. Cooper et al. (1978) found that the application of emphatic stress to either the word ending in a stop (or fricative) or to the word beginning with a glide reduced the occurrence of palatalization. He found this effect more pronounced when the word beginning with a glide was emphatically stressed, which he attributed to the speaker's desire to more clearly articulate the word-initial, as opposed to the word-final, segment of an emphasized word.

A later study of the influence of stress and speech
rate on occurrence of palatalization, Cooper et al. (1983), replicated the results of their earlier study, and also found palatalization to be inhibited at slower rates of speech. The researchers offered two explanations for their results. One was that this effect is due to speakers' restricted look-ahead, "prohibiting the speaker from simultaneous access to phonological information on both sides of the key word boundary" (Cooper et al., 1983, p. 1729). The alternative explanation was that the segmental lengthening at slower rates of speech is incompatible with the segmental shortening caused by palatalization. There is, however, no evidence that palatalization caused by fricatives is sensitive to prosodic factors, as attested examples of this assimilation in the literature involve word pairs in which adjacent syllables are stressed, e.g. "gas shortage".

It should also be noted that in addition to requiring some kind of prosodic unity, palatalization caused by glides may also require some kind of grammatical unity (Kaisse, 1985). There are, however, studies (e.g. Zue and Shattuck-Hufnagel, 1980) which attest to the possibility of palatalization in such unusual phrases as "sweet Yosemite" (which incidentally does adhere to the prosodic criterion of stressed syllable followed by unstressed syllable). There are, to my knowledge, no studies that claim palatalization by fricatives requires grammatical closeness.
The above observations are summarized as follows:

**Palatalization by glides**

1) perseverative voicing assimilation only
2) anticipatory place assimilation only
3) not sensitive to segmental conditioning factors
4) sensitive to suprasegmental conditioning factors

**Palatalization by fricatives**

1) anticipatory voicing assimilation
2) anticipatory, but also perseverative when palatalizing fricative-stop clusters
3) sensitive to segmental conditioning factors
4) not sensitive to suprasegmental conditioning factors

4.3 **Inter-word Palatalization: The Interaction of Phonetics and Phonology**

Although palatalization by glides and by fricatives is a single rule when described in terms of features, the phonetic and phonological observations above suggest it sometimes acts as two distinct rules.

I believe this is because inter-word palatalization actually resulted from two separate phonetic processes that became phonologized into one rule. Stop + glide palatalized sequences are likely to have originated from the affrication of stops in a palatal environment. Ohala (1983) has pointed out the strong tendency for the release portion of stops preceding high front vowels to become
affricated. This is because the high velocity of the airflow created upon release of a stop lasts longer when the vowel following the stop is close rather than open. He cites among evidence for this tendency the Japanese affricate allophone of the dental stop preceding high vowels /i, u/, e.g. /tu ti/ = [tsu ti] "ground".

Furthermore, Ohala points out (p. 204), close glides are prone to the development of frication because they frequently have a constriction even smaller than vowels. Among the phonological evidence for this phonetic tendency is the [j] - [ʒ] variation among dialects of Spanish: Andalusian [ka ba jo] "horse" vs. Argentine [ka ba jo]. This phonetic process then became phonologized and, to some extent, frozen in certain prosodic environments, possibly also with the additional criterion of high-frequency words. This would explain the sensitivity to prosodic and grammatical conditioning factors that palatalization by glides exhibits.

On the other hand, palatalization of fricatives is a coarticulatory process that became phonologized into an assimilation rule. For this reason it does not require a fixed prosodic or grammatical environment in which apply, as this is not characteristic of assimilation rules in English.

The differences in voicing assimilation between the two kinds of palatalization can also be accounted for by
the phonologization of two distinct phonetic processes. The devoicing occurring in palatalized fricatives is fostered by the aerodynamic constraints on fricative voicing. The aerodynamic requirements for frication, a higher oral pressure with respect to atmospheric pressure, are antithetical to those for the maintenance of voicing, namely a high subglottal pressure and a low oral pressure: hence the tendency toward devoicing of fricatives.

Voicing of the palatalized sequence resulting from underlying stop + glide is identical to the voicing of the underlying stop. This is originally not an assimilation, but rather an affrication, and it is therefore expected that the voicing of the surface affricate will agree with that of the affricated segment.

The two kinds of palatalization also differ because the phonological result of stop + glide palatalization involves change in both manner and place, while the result of fricative + fricative palatalization involves change in place of articulation alone.

But this phonetic explanation itself does not account for the durational findings of the experimental studies: they are phonological properties. The temporal variation of the palatalized sequences suggest that they are an integral part of the segmental specification, and not, as is generally assumed in phonology, a suprasegmental effect.

A frequent example cited for rejecting the
incorporation of a segment's duration into a phonological description is that of vowel length before voiced consonants. The fact that vowel duration is longer preceding voiced consonants is considered an example of phonetic implementation, as opposed to part of the phonological description of the language. Yet, Chen (1970) noted that although this seems to be a phonetic tendency, English has enhanced and exaggerated this effect to the extent that it is more obvious in English than in other languages. In other words, the phonetic tendency of increased vowel duration preceding voiced consonants has been phonologized.

I hypothesize that something similar is occurring in the duration of palatalized sequences. Because fricatives (Klatt, 1974) and affricates (see Experiment 2) show allophonic durational variation at word boundaries, and because this palatalization occurs at word juncture, durational properties became part of the phonological specification of the inter-word rule.

4.4 Experimental Summary

"Fast-speech" inter-word processes are a point of convergence between phonetic implementation (low level effects) and phonological rules (high level effects). However, few studies of these rules have paid attention to the fine detail of their implementation: most phonological accounts are basically impressionistic.
The purpose of the three experiments described in Chapter 3 was to examine inter-word palatalization experimentally, to better understand how phonetic factors present in word boundary allophones are integrated into the production of phonological rules across word boundaries.

The specific claims I tested were 1) that interword palatalization had both a discontinuous and a continuous component, and 2) the discontinuous component was the assimilation of place of articulation, and 3) the continuous component was durational.

I studied the following examples of palatalization: (1) stop + glide sequences, (2) fricative + fricative sequences, (3) fricative + glide, and (4) affricate + fricative. I examined two acoustic phonetic properties at the palatalization sites. F2 endpoint transitions into consonants would indicate whether the rule was discontinuous or not. Durational properties of the consonants would indicate whether palatalization comprised a temporal or continuous component.

The following is a brief summary of the results and conclusions for each experiment.

4.4.1. Experiment 1

I compared mean F2 endpoints at palatalization sites (palatalized sequences resulting from underlying stop + glide, e.g. "bought you") with those into alveolar stops (e.g. "bought Timothy") and into palato-alveolar affricates
(e.g. "botch it"). I found that transitions into palatalized sequences did not differ substantially from those into palato-alveolar affricates.

Palatalization of stops is described in the literature as a feature-changing assimilation rule. Experiment 1 showed this to be the case acoustically.

### 4.4.2. Experiment 2

Palatalized stop + glide sequences cannot contrast durationally with other phonemes, there being no geminate affricates in English. However, I was interested in whether temporal properties of palatalized sequences and affricates varied according to their position in words, i.e., whether durations were sensitive to word boundaries.

I compared durations of affricates (preceding vowel, closure and frication) resulting from palatalization of stop + glide sequences with those of affricates in word-initial, -medial and -final positions. Specifically, I tested three hypotheses.

The first was that inter-word stop + fricative clusters (e.g. "bought ships") have different durations than affricates in word-initial position (e.g. "gnaw chips"). I found that durations of vowels preceding clusters were shorter than those preceding affricates, which is likely due to the fact that vowels preceding word-initial affricates are in open syllables.

I also found durations of the frication portion of
word-initial affricates to be shorter than those of the fricative in stop + fricative clusters.

The second hypothesis tested was that word-initial and word-final affricate allophones differed durationally. I found preceding vowel durations to differ, which was expected in that the vowel preceding the word-initial affricate was in an open syllable. I also found, however, that speakers produced allophones with differing durations of the consonantal portions as well. Closure portions of word-final allophones were shorter than word-initial allophones, but frication portions longer. These results suggest that the durational properties of affricates do not mimic those of fricatives: Klatt (1974) reported word-initial fricative allophones to have longer durations than their word-final counterparts.

The third hypothesis compared durations of palatalized sequences with those of affricates in word-initial (e.g. "gnaw chips"), -medial (e.g. "digits"), and -final (e.g. "botch it") positions. In comparing palatalized sequences to word-medial affricates, I found a large degree of individual variation. The only strong effect for most speakers was that closure durations of palatalized affricates were longer than those of word-medial affricates. This was in agreement with findings reported in the literature that closure portions of other segments, notably /t/ allophones, were shorter in word-medial
position.

In comparing the durations of affricates resulting from palatalization (e.g. "bought you") to word-final affricate allophones (e.g. "botch it"), I found few systematic differences. However, the durational differences between palatalized sequences and word-initial affricates show palatalized sequences to have shorter preceding vowel durations, shorter closure durations and shorter frication durations.

The results of Experiment 2 show there is evidence that 1) affricates at word boundaries differ durationally from clusters, 2) that affricates show durational allophonic variation at word boundaries, and 3) that palatalized sequences differ from word-initial allophones, but the evidence that they share durational properties with word-medial or -final allophones is inconclusive.

4.4.3. Experiment 3

Experiment 3 consisted of two parts. In the first part I compared mean F2 endpoints preceding palatalized sequences (e.g. "toss sheepskins") to those preceding palato-alveolar (e.g. "josh Sheila") and alveolar fricatives (e.g. "boss seems"). I found endpoints at palatalization sites to be significantly higher than those of alveolar fricatives.

I also compared mean F2 endpoints preceding anticipatorily palatalized sequences (e.g. "toss
sheepskins") to those preceding perseveratively palatalized sequences (e.g. "squash steamer"). I found that these endpoints did not differ significantly.

In the literature, palatalization of fricatives is described as a feature-changing rule. I found the assimilation of place of articulation to be complete, and both anticipatorily and perseveratively palatalized fricatives showed this effect.

In the second part of the experiment I tested the hypothesis that palatalization of fricatives had a temporal, continuous component: durations of palatalized fricatives (e.g. "toss sheepskins") are not equivalent to geminates (e.g. "josh Sheila"), but somewhat shorter. I compared the durations of palatalized fricatives and geminate palato-alveolar fricatives. I found durations of the palatalized fricatives to be significantly shorter than those of the geminates.

I also compared durations of perseveratively palatalized fricatives (which are followed by a stop consonant, as in "squash steamer") with fricatives palatalized anticipatorily by a yod (e.g. "toss you") and found the former not to be significantly shorter than the latter.

To my knowledge, there have been no studies of fricatives palatalized by affricates. I examined the durational properties of palatalized sequences resulting from fricatives palatalized by affricates, as in "watch
steel", and compared them to those of palato-alveolar affricates with no underlying representations, for example "botch it"). I found that for most speakers, durations of the palatalized affricates were significantly longer than those of the singleton affricates, even though they were adjacent to a stop consonant: "watch steel" → [wạʧtil], which would be likely to shorten the duration of the preceding frication.

These studies of the durational properties of palatalized fricatives suggest that length of the palatalized allophone is an integral component of its specification.

4.5 The Phonetic Status of Postlexical Palatalization

In Chapter 2 I reviewed certain controversies about the nature of postlexical rules. Kiparsky (1985) suggested that a single rule could be discontinuous when applied lexically and continuous when applied postlexically. However, few examples of how this operates in English are offered, and few examples of continuous phonetic parameters are given. One possible reason for this is that, as Liberman and Pierrehumbert (1984) pointed out, there are a dearth of experimental studies designed to investigate these kinds of questions. The results of the acoustic-phonetic experiments described in Chapter 3 showed that the durational patterns of inter-word palatalized sequences were not the same as the durational patterns
specified in the lexicon, and thus must be considered a part of the postlexical rule.

A possible question arising from the above conclusions is their robustness: are the subphonemic allophonic variants evidenced at word boundaries perceptually salient? If not, how relevant are the acoustic findings?

Although generative theories of phonology (Chomsky and Halle, 1968) presumed an abstract grammar neutral with respect to speaker and hearer, more recent phonological writings have suggested this is not the case. Ohala (1981, in press) has found the origins of certain dissimilation and assimilation rules in the perceptual domain. Others (Dinnsen, 1985) point out that phonological descriptions of rule-governed allophonic phenomena must of necessity be production oriented, as these different phonetic realizations of the same phoneme are presumed to describe production differences not generally self-discriminable by native listeners. Without presuming that rules must operate in one domain or the other exclusively, it is clear that direct examination of the speech signal is a relatively untapped resource for understanding how phonological rules are implemented by speakers. They are also a valuable tool in establishing principles for parsing the signal into words. This approach to phonological rules show that experimental phonetics and phonology need not be considered disjunctive sets: an integrative approach is vital to a greater understanding of connected speech.
processes.
REFERENCES


Press.


54: 1235-47.


Pesetsky, D. 1979. Russian morphology and lexical theory. unpublished ms., MIT.


