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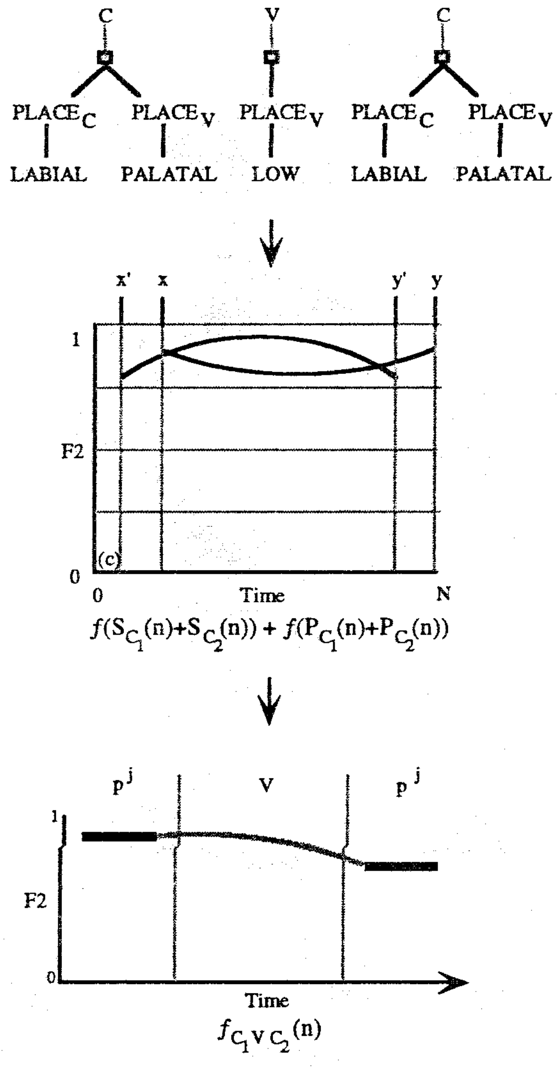

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by

John D. Choi

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ABSTRACT

Phonetic Underspecification and Target-Interpolation:
An Acoustic Study of Marshallese Vowel Allophony

by

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Doctor of Philosophy in Linguistics
University of California, Los Angeles, 1992
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Marshallese exhibits strict distributional restrictions on surface vowel quality as a function of adjacent consonantal secondary articulations. This vowel allophony is accounted for in terms of a phonetic underspecification and target-interpolation paradigm. The vowels are phonologically analyzed as lacking an inherent specification for the front~back parameter, and this underspecification is argued to persist into the phonetic component. Variation along the front~back dimension is derived by interpolation from the surrounding consonantal targets. General linear statistical methods are used to test the predictions made by this model in the acoustic domain. These tests confirm that variation in F2 is within the parameters predicted by the underspecification hypothesis. The data also show consonant-to-consonant coarticulation and consonantal locus asymmetries. A least-squares curve-fitting procedure is then used to characterize the trajectories as time-varying functions. The trends that are observed in the data are captured by a linear additive model based on the effects of asynchronously timed primary and secondary consonantal constrictions, coupled with the effects of variation in constriction size associated with vowel height. Crucially, the model does not include a vocalic F2 target.

CHAPTER 1: INTRODUCTION

This dissertation examines the concept of phonetic underspecification within a target-interpolation model of phonetic representation. The data for this study are drawn from Marshallese, an Austronesian language. Marshallese exhibits systematic restrictions in the distribution of its phonetic vowels, such that surface variation along the front-back dimension is contextually determined by the secondary articulations of adjacent consonants. It is proposed that the vowels underlyingly lack intrinsic front-back features and that this underspecification persists phonetically, such that the corresponding F2 trajectory is derived by interpolation between surrounding consonantal targets across a partially underspecified vowel.

Certain predictions are made by this underspecification account of Marshallese vowel allophony. Instrumental and statistically based analytic methods are used to explore these predictions in the acoustic domain and to test the hypothesis that the Marshallese vowels can be modeled without reference to a vocalic F2 target in CVC contexts. These analyses show that the predictions do obtain in the acoustic data, providing *prima facie* evidence in support of the underspecification hypothesis.

A number of other related issues in linguistic phonetic and phonological theory are also addressed in this study. Included among these is coarticulation. While numerous studies, cited below, have attended to local consonant-to-vowel, vowel-to-consonant, and non-local vowel-to-vowel coarticulation, few studies have investigated consonant-to-consonant coarticulation across vowels. Given the strong consonantal influence on vowels that has been reported in Marshallese, it is potentially the case that this influence extends across the vowels and influences non adjacent consonants as well. The extent to which this influence can be modeled with or without reference to a vocalic F2 target relates to the question of phonetic underspecification. More generally, the study will also provide data regarding the effects of consonantal secondary palatalization and velarization on vowels.

In so far as the analysis of vowel allophony is conducted within a target-interpolation model, the study is also concerned with acoustic-phonetic representations. Acoustic targets for secondary consonantal articulations are estimated and the vocalic F2 trajectories are defined as time-varying functions. While much attention has been paid to the question of targets, the issue of interpolation has not been investigated as thoroughly. Given that the nature of interpolation greatly affects the definition of targets in any target-interpolation model, it follows that a detailed study of interpolation will contribute to theories of phonetic representation.

This study also bears on vowel typology. Vertical vowel systems like that of

Marshallese are unusual and typologically interesting. Indeed, some studies devoted to vowel typology have rejected the possibility that vertical vowel systems exist in natural language (e.g., Crothers 1978). The current study, by providing a quantitative characterization of front-back variation in the vowels of Marshallese based solely on a phonemic height contrast, will be able to offer evidence in favor of the claim that vertical vowel systems do in fact occur in natural language.

The dissertation is organized as follows: In Chapter 1, the theoretical framework and general background relating to coarticulation and underspecification are presented. In Chapter 2, we turn to Marshallese and explain why it is an interesting test case for the underspecification hypothesis. A phonetic underspecification account of vowel allophony is proposed, and the predictions made by the account are outlined. A statistical methodology designed to test the predictions made by the proposed account is presented in Chapter 3. This methodology is then applied to a corpus of acoustic data, collected from four speakers. The acoustic characteristics of the medial long vowels are also examined and shown to exhibit trajectories which suggest that a target is present, providing a contrast to the targetless short vowels. Lastly, a curve-fitting procedure is used in Chapter 5 to examine the shape of the F2 trajectory more closely in the partially underspecified vowel. These results are considered in light of the underspecification hypothesis and the assumption that the interpolation function is linear. The main results of this study are summarized in Chapter 6 and their relevance to the theoretical issues introduced above are discussed.

1.1. BACKGROUND

1.1.1. COARTICULATION AND UNDERSPECIFICATION

The study of coarticulation, a term attributed to Menzerath & de Lacerda (1933), can be traced back to the turn of the century (Hardcastle 1981). Difficulties in segmenting the speech signal were attributed to the complexities of articulatory dynamics as early as 1876 (Sievers 1876). The notion of overlapping or simultaneous articulations is implicit in Scripture's (1902: p. 372) discussion of work on CV syllables by Laclotte: "...the tongue takes for the beginning of the work of articulation for the syllable the position necessary for the vowel and maintains it through the consonant and its explosion." The first study of transconsonantal vowel-to-vowel coarticulation can also be traced back to Laclotte (1899) who showed that the articulation of the initial vowel in /eba/ and /ebi/ differed.

These areas of investigation persist to this day in phonetic theory. Considerable research has been devoted to coarticulation (Daniloff & Hammarberg 1973; Kent & Minifie 1977), particularly with respect to nasalization (Moll & Daniloff 1971; Kent, et al. 1974; Benguerel, et al. 1977a, 1977b; Bell-Berti, et al. 1979; Huffman 1990; Cohn 1990; Bell-Berti & Krakow 1991; *inter alia*) and lip-rounding (Benguerel & Cowan 1974; Bell-Berti & Harris 1982; Lubker & Gay 1982; Boyce 1988; *inter alia*). These phenomena involve relatively non-complex gestures that are relatively easy to identify and separate from other components, making them easier to monitor and track given the current technology.

Other areas that have received considerable attention are vowel-to-vowel coarticulation (Öhman 1966, 1967; Kent & Moll 1972a; Gay 1977; Purcell 1979; Magen 1989; Manuel 1990; Choi & Keating 1991; *inter alia*) and consonant-vowel coarticulation (Stevens & House 1962; Lindblom 1963; Schouten & Pols 1979; Sussman 1991; *inter alia*). A recurrent theme in this and other coarticulation research has been the notion that coarticulation arises from the lack of an antagonistic gesture which would otherwise block or impede the influence of the coarticulating feature. For example, the relative "transparency" of the consonant in transconsonantal vowel-to-vowel coarticulation can be interpreted in terms of the lack of a tongue-body specification in the production of the consonant. If this is true, then we would expect such coarticulatory effects to be blocked in the case of contrastive secondary articulations in a consonantal system. In fact, this was the proposal originally made by Öhman (1967) to account for the lack of coarticulation in Russian which retains a palatalized vs. nonpalatalized consonantal contrast (Jones & Ward 1969). Choi & Keating (1991) tested this prediction and found very small carryover effects in Russian and Bulgarian, which were nonetheless statistically significant. Given these results, they concluded that while secondary articulations do not absolutely block vowel-to-vowel coarticulation, there is a definite inhibition or weakening in the effect when they are present.

The presence or absence of antagonistic gestures is dependent on the phonemic oppositions and phonotactic constraints that exist in a given language, and it has been posited that the degree of coarticulation in languages differs depending on the system of contrasts in that language (Cohn 1990; Manuel & Krakow 1984; Manuel 1990). A comparison of Ndebele, Shona and Sotho by Manuel (1990) showed lesser degrees of anticipatory coarticulation in Sotho, the language with a more crowded vowel space. The results are explained in terms of output constraints that govern variability in the magnitude of coarticulation, based on the assumption that languages strive to maintain acoustic distinctiveness (Lindblom 1983; Lindblom & Engstrand 1989; Stevens 1972, 1989). This hypothesis is also present in formal phonological theory, although the underpinnings and motivation for the notion of underspecification are somewhat different from those in phonetic theory.

The affinity between phonological and phonetic underspecification is discussed by Keating (1988) who formally captures the relationship by proposing that phonological underspecification may persist into the phonetic component; i.e. underspecified representations are not necessarily assigned values by fill-in rules. Rules of this type have previously been thought to be required before a phonetic module could interpret phonological specifications into phonetic ones. Instead, the phonetic values for the underspecified segments may be independently derived by principles of phonetic implementation. Evidence for this proposal is based on the observed F2 trajectories in segments which are posited as lacking F2 targets, as in the case of the glottal fricative /h/ in English /VhV/ sequences. Glottal fricatives are typically thought to be phonologically unspecified for supralaryngeal features. Consequently, they lack any articulatory targets (e.g. tongue body specifications) or acoustic targets (e.g. F2) which would perturb an otherwise smooth and continuous trajectory from the initial vowel to the following vowel. Stated in other terms, we would expect that the spectral shape of [h] could be entirely predicted from the adjacent vowels.

1.1.2. CONSONANT-VOWEL INTERACTIONS

Phonetically, consonant-vowel interactions are pervasive and they have been the focus of numerous studies. Much of the early work on targets/loci was concerned with consonant-vowel transitions and the effects that certain vowels had on consonantal targets and *vice versa*. Stevens & House (1962), in examining the hypothesis that locus frequencies reflected the acoustic correlates of complete articulatory closure, observed that the locus values for bilabials, alveolars and dentals varied as a function of the following vowel in English. They also found systematic shifts in the vowel formant frequencies depending on the consonant and concluded that "...the extent to which an ideal articulatory configuration is achieved for a vowel depends upon the effective 'distance' that the articulators must traverse during the various phases of the syllable between the initial consonant, the central syllabic nucleus and the terminal consonant" (p. 120). This phenomenon was explored further by Lindblom (1963) who postulated that if vowel targets represent some physiological invariance, and control of the articulators is associated with neural events in a one-to-one correspondence, then the extent to which articulators reach their target positions depends on the relative timing of the excitation signals. If these signals are far apart in time, the response may become stationary at individual targets. If, on the other hand, instructions occur in close temporal succession, the system may be responding to several signals simultaneously, resulting in coarticulation. The failure to reach these positions due to physiological limitations is realized acoustically as undershoot.

The degree to which vowel quality is affected by adjacent consonants seems to be language specific. For example, Schouten & Pols (1979) observed the spectral characteristics of the "steady-state" portions of vowels in CVC words in Dutch and found that they do not vary systematically as a function of the surrounding consonants. At the other end of the spectrum, Choi (1992) observed systematic variation in the center of short vowels as a function of the preceding consonant in Kabardian, a Caucasian language.

A central hypothesis in this dissertation is that languages with vertical vowel systems, like Marshallese and Kabardian, will systematically exhibit a high degree of consonant-to-vowel coarticulation. This is based on the assumption that coarticulation is strongest in the absence of antagonistic gestures. Since vertical vowel systems by definition lack a front/back distinction, the tongue body is not constrained by the gestural requirements necessary to make this distinction in the production of the vowel, leaving the articulator free to meet the demands of the surrounding segments.

It is interesting to note that Kabardian (Kuipers 1960; Halle 1970; Colarusso 1978a, 1988b; Choi 1992) has also been phonologically analyzed in terms similar to those that will be proposed here for Marshallese, and that it is often cited as the classic example of a vertical vowel system (Crothers 1978; Trubetzkoy 1939). Other languages which have been analyzed as exhibiting vertical vowel systems include the northwest Caucasian languages Abkhaz (Allen 1956) and Ubykh (Catford 1977); the Papuan languages Abelam (Laycock 1965), Iatmul (Staalsen 1966; Foley 1986) and Haruai (Comrie (FORTHCOMING)); Margi (Maddieson 1987), a Chadic language; and the Arandic languages Kaytetj (Koch 1986) and Arrente (Ladefoged & Maddieson 1990). Not surprisingly, all of these languages have been described as exhibiting vowel allophony that is contextually determined by adjacent consonants.

A related question concerns the number and quality of consonants in these languages; i.e., is it the case that languages with vertical vowel systems exhibit (i) large consonantal inventories and (ii) secondary articulations (e.g., [PALATAL], [VELAR]) in their consonantal system? Vertical vowel systems are small (either 2 or 3 vowels) and it is frequently assumed that there is an inverse correlation between the number of vowels and consonants in a language so that, e.g., a language with a small number of vowels will typically have a large number of consonants. Maddieson (1984) found this assumption to be unconfirmed.

Justeson & Stephens (1984) also argue that there is no evidence for a balance or correlation between vowel and consonant inventory sizes. With respect to the phonetic features found in the consonant system of vertical vowel languages, it is certainly true that the northwest Caucasian languages exhibit an abundance of secondary articulations as well as uvulars and pharyngeals. Marshallese also exhibits secondary palatalization, velarization and rounding. The other languages listed above are somewhat more conservative in the consonantal oppositions they maintain. For example, the Papuan languages typically have consonants at four places of articulation, bilabial, alveolar, (pre)palatal and velar. Secondary articulations are not reported. This is the case in Iatmul, described by Staalsen (1966), and illustrated in Table 1.1.

TABLE 1.1. IATMUL CONSONANTAL INVENTORY (AFTER STAALSEN 1966)

	bilabials	*coronals*	*palatal*	*velars*
stop	p	t		k
fricative	β	s		ɣ
nasal	m	n	ɲ	
approximants	w	l	j	

The existence of languages such as Iatmul suggests that it is not the case that vertical vowel systems somehow entail complex consonantal systems riddled with secondary articulations. Hypothetically, however, languages with consonantal systems that complement a sparse vocalic system will exhibit stronger consonantal effects on vowels.

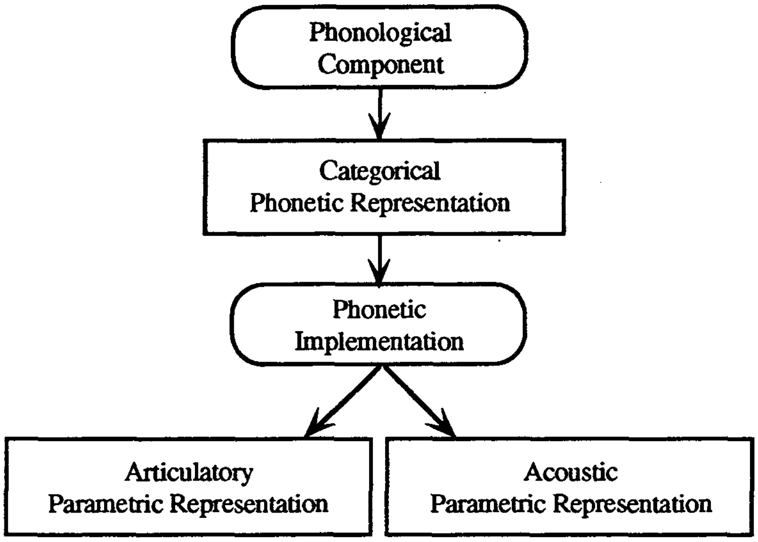
1.2. THEORETICAL FRAMEWORK

It has been a long-standing axiom in phonological theory that speech is a sequence of discrete, categorical entities. This assumption has yielded much insight in phonological theory and continues to do so. Attempts to explore speech production and the speech signal in similar terms, however, have proven less accommodating given the continuous, quantitative nature of phonetic parameters. Nonetheless, much phonetic theory remains couched in terms of sequentially arranged articulatory/acoustic states or targets. The account of Marshallese vowel allophony that will be argued for in this dissertation is embedded in one such model of phonetic representation, namely a target-interpolation model.

1.2.1. PHONETIC COMPONENT

Phonetic representations are linguistic structures, in so far as they are derived by a component of the grammar. The phonetic component is assumed to consist of rules which map the output of the phonological component to a level of parametric phonetic representation (Keating 1990b). This is illustrated in Figure 1.1. Phonetic representations differ from discrete, categorical phonological representations in that they are continuous in time and space (Pierrehumbert 1990). It is further assumed that these parametric representations consist of targets and interpolation functions which govern movement from target to target.

FIGURE 1.1. THEORETICAL FRAMEWORK (AFTER KEATING 1990B)



1.2.2. PHONETIC REPRESENTATIONS

1.2.2.1. TARGETS

The concept of a phonetic target or locus can be traced back to the work of Potter, Kopp & Green (1947) and has been adopted in numerous studies (Delattre, Liberman & Cooper 1955; Stevens & House 1962; Stevens, House & Paul 1966; Lindblom 1963; MacNeilage 1970; Sussman, et al 1991; *inter alia*). In the current study, phonetic targets are viewed as abstract representational units with both spatial and temporal properties. Specifically, they are defined in the following terms: For any given segment, there is a phonetic space which can be characterized in terms of a finite set of phonetic parameters associated with that segment. If we define a parameter P as a continuum from 0 to 1, then a target T can be defined as a point on this continuum, such that $0 \geq T \geq 1$. T specifies a segment's value for the parameter. Typically, targets have been specified as points on this continuum. However, Keating (1990a) has also proposed that targets represent a range in the continuum that defines all possible contextual variation. Although the point-model is assumed in this study, it should be pointed out that the data presented are not inconsistent with Keating's window-model.

In the time domain, targets are associated with segments and consequently participate in the intrinsic precedence relations that obtain in any segmental representation. In addition to the gross linear ordering relations that targets participate in, there is also evidence that targets may be time-aligned with segment-internal landmarks or structures (Huffman 1990; Kingston 1990; Steriade 1992).

Implicit in the model illustrated in Figure 1.1 is the assumption that targets are projected from distinctive features. This strong position has been explicitly taken by Keating (1988; 281): "...identifiable targets in a physical signal reflect feature values, in that each feature value, and only feature values, get targets of some kind". It is important to note that the mapping from distinctive features to phonetic targets involve nonlinearities which are quite complex (Stevens & Blumstein 1978, 1981; Blumstein & Stevens 1985; Lisker 1985; Stevens 1980; Ladefoged & Lindau 1986; Stevens & Keyser 1989). There are, however, a number of parameters which have been shown to strongly correlate with certain features.

Two acoustic-phonetic parameters which have been shown to correlate with distinctive features are the first formant frequency (F1) and the second formant frequency (F2). F1 correlates with the categorical specification denoted by the features [±HIGH; ±LOW], while F2 has been shown to correlate with the categorical specification denoted by the feature [±BACK] (Ladefoged 1972; 1982). It is well known that these acoustic parameters are not in a one-to-one relation with the position of the tongue body along the horizontal and vertical dimensions, and it has been argued (Bladon & Ladefoged 1982) that two-formant vowel models are inadequate representations of vowel quality. However, given that the study is restricted to the effects of consonantal secondary palatalization and velarization on vowels, it is argued that a characterization of the variation observed in F1 and F2 should be sufficient to address the issues of concern.

It is worth mentioning at this point that this dissertation is not concerned with the issue of relating acoustic and articulatory targets, beyond the fact that the phonological features discussed above have some basis in articulation and not acoustics (Chomsky & Halle 1968; Catford 1981; Fischer-Jørgensen 1985; cf. Jakobson, et al. 1952; Ladefoged 1976, 1989; Nearey 1978). The mapping from articulatory to acoustic representations is an area of investigation which is outside the domain of this study and for which there is a large body of literature (Fant 1960, 1965; Stevens 1972, 1989; Ladefoged, et al. 1978; Mrayati, et al. 1988; Carré & Mrayati 1990, 1991; *inter alia*). And although the discussion of acoustic targets and the interpolation function will draw on this literature for possible explanations, it should be made clear that the modeling in this study will be restricted to target-interpolation in the acoustic domain.

1.2.2.2. INTERPOLATION

Interpolation refers to the movement from target to target; in this study, interpolation is examined in the context of movement from F2 target to F2 target in the acoustic domain. A number of studies have been devoted to the dynamic characteristics of F2 in diphthongs (Collier, Bell-Berti & Raphael 1982; Dolan & Mimori 1986; Gay 1968; Holbrook & Fairbanks 1962; Lehiste 1967; Lehiste & Peterson 1961; Lindau, et al. 1985; deManrique 1979; Piir 1983; Ren 1986). These studies vary in their treatment of the F2 trajectory; some examine F2 at the initial, mid and final points of the diphthong while others take into consideration other factors that deal with more dynamic characteristics of the trajectory, such as rate and direction of change over time.

Research focusing specifically on characterizing formant trajectories as time varying functions has been conducted by Broad & Fertig (1970), Broad (1984) and Broad & Clermont (1987). These studies, based on English C_1VC_2 utterances, model the F2 trajectory in terms of a locus for each consonant and a vowel target. The formant transitions from C-to-V and from V-to-C are then scaled proportionally to the differences between vowel targets and consonant loci, following the work by Stevens & House (1963). Lindblom's (1963) observation that consonantal effects on formants at the vowel midpoint decay exponentially with vowel duration (dependent on speech rate) is also implemented by characterizing the transition functions f and g as exponentials. The resulting CV and VC transition functions are placed in a linear overlap relation to the vowel target. Similar work has been conducted by Fujisaki & Higuchi (1979) and Imaizumi, et al. (1991).

The value assigned to a target can be largely influenced by the characterization of the interpolation function, and vice versa. This relationship is illustrated in two different approaches to phonetic representations, that of contextual-target shifts (Pierrehumbert 1980; Pierrehumbert & Beckman 1988) and that of undershoot (Lindblom 1963; Stevens & House 1963). The undershoot model is mechanistically motivated and states that contextual variation is the product of physiological and neurological limitations which prevent attainment of target values. This contrasts with target shift models which state that the targets themselves are sensitive to evaluation procedures which define contextually-triggered shifts in target value. An extensive study of target evaluation and interpolation rules is found in Pierrehumbert's (1980) modeling of English intonation. Pierrehumbert's model includes interpolation rules which are dependent on target values and target positions in time. Interestingly, the interpolation rules also seem to reference underlying tones, generating differences in the interpolation between L-H (linear interpolation) and H-H (sagging interpolation) in cases where the initial H is lower in absolute value than the second. This framework has undergone further development in Beckman and Pierrehumbert (1986) and Pierrehumbert and Beckman (1988). These later models, based on Japanese, utilize a single linear interpolation rule which is supplemented by smoothing.

A number of different interpolation functions have also been implemented in parametric synthesis systems. Such systems are very similar to the target-interpolation models being discussed. Holmes, et al. (1964) calculate a boundary target based on transformations of specified steady-state targets. In addition to a steady-state target, each segment is assigned an 'internal' transition duration, a weighting coefficient and a 'fixed contribution' coefficient. When two segments are concatenated, the weighting coefficients are compared to determine which segment is 'dominant'. A predefined proportion of the steady-state value of the weaker element is then added to the 'fixed contribution' for the dominant segment. This sum is the boundary target value. Linear interpolation is then used to calculate the parameter values between the steady-states and the boundary values.

The MITalk system, outlined in Allen, et al. (1987), applies four pre-defined smoothing templates to concatenated targets. In the case of CV syllables, for example, the system assigns a target value for the consonant and a target steady-state for the vowel. A locus equation is then used to determine formant values at the CV boundary. A template is subsequently imposed on these values defining the trajectory from target to target. It is worth noting that MITalk incorporates readjustment rules so that targets are always reached (similar to Pierrehumbert). Holmes' system, on the other hand, is based on invariant targets and utilizes undershoot to attain variation (similar to Lindblom).

Another interesting approach is described by Jordan (1986) who explores coarticulation using a parallel distributed processing strategy. The problem is seen as one of serial order or the implementation of parallel interactions across time. The network's learning process is based on a list of value constraints on the output units. The constraints, associated with phoneme specifications as outlined by Ladefoged (1982), appear as regions in a state space through which continuous trajectories must pass. This is reminiscent of Keating's (1990a) windows model. To approximate a continuous system, several time steps are inserted between steps at which constraints are imposed, during which 'don't-care' constraints apply so that the network is effectively free running. During the learning process, parallel interactions between phonemes can arise as long as the value constraints are not violated. The system freely generates trajectories, changing its parameters until the constraints are met.

The model is particularly interesting in that transitions are dependent upon the knowledge encoded in the definitions of the phonemes. The result is a model which does not require explicit interpolation algorithms external to the phoneme. The locally critical transitions are determined by the value constraints. In the terms which we have been using, this can be translated as saying that local transitions across immediately adjacent segments are constrained by the phonemic specifications inherent to the segments. Moreover, the 'don't-care' constraints allow what Jordan refers to as accommodated movements, or movements that are accommodated within the sequential pattern defined by the locally critical articulatory transition. This suggests that 'don't-care' constraints can be seen as the implementation of underspecification; the trajectories are defined solely in terms of the preceding and following targets (value-constraints) and are unperturbed otherwise when proceeding through a 'don't-care' space.

1.2.3. COPRODUCTION MODELS

The models discussed contrast with another genre of models referred to as "coproduction" or "gestural" models (Fowler 1980; Bell-Berti & Harris 1981; Browman & Goldstein 1986; Saltzman & Munhall 1989; *inter alia*). The difference between these theories is captured in their respective accounts of coarticulation. In coproduction theories, coarticulatory effects are interpreted in terms of overlapping onsets and offsets of articulatory gestures. These gestures comprise the "core structure" (Bell-Berti [to appear]) of segments. An important aspect of the coproduction model is that it allows variation in timing across the articulators. Thus, while the individual articulations that make up a segment can be viewed as synchronous, it is also the case that different articulators can exhibit different onsets and offsets. In short, contextual variation is derived by overlap across segments, and not by extrinsic changes in a gesture's specification. This contrasts with the target models which derive surface variation in terms of rules which alter the phonetic values of the targets themselves.

Theories that fall under the general rubric of coproduction models differ in their acceptance of the underspecification hypothesis. Boyce, et al. (1991), for example, have rejected the underspecification hypothesis, claiming instead that segments retain a specification for all articulators. In contrast to this position is the Articulatory Phonology model developed by Browman & Goldstein (1987; 1991). Here, the gestural structures that comprise the basic phonetic/phonological units are inherently underspecified, in so far as there are intervals of time during which the value of a given tract variable is not being actively controlled by the system. This tract variable can, nonetheless, exhibit change resulting from coupling with a tract variable which is under active gestural control and/or an articulator-specific 'neutral' state.

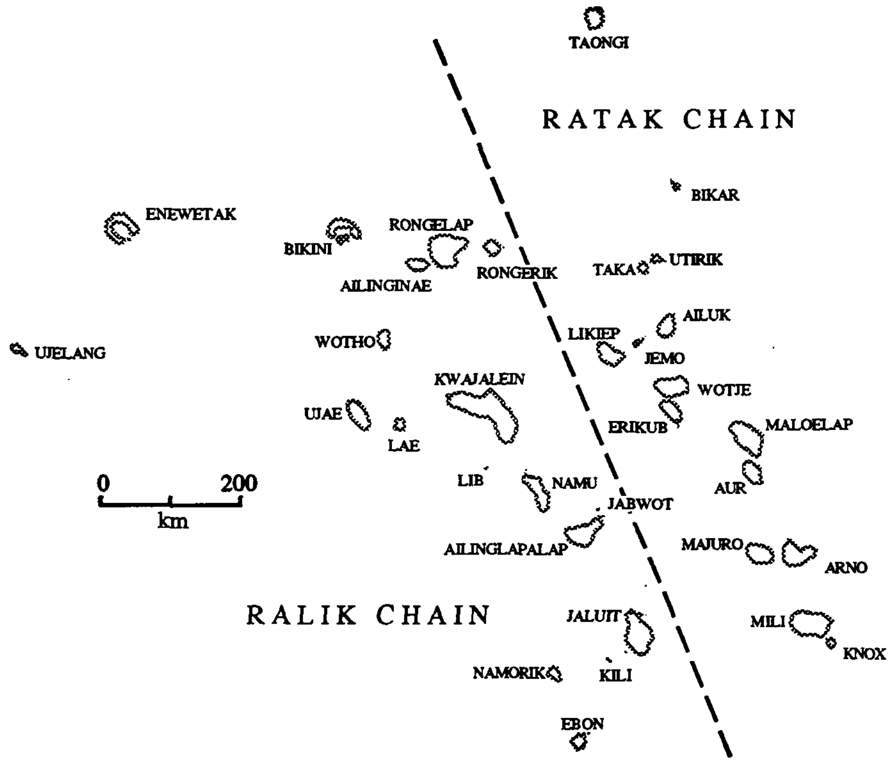
Browman and Goldstein's model is articulatorily based, and as such, differs from the acoustic modeling that is being attempted in this dissertation. It is worth mentioning, however, that the interpolation in their model is mechanically motivated, based on a damped mass-spring model which is claimed to capture the dynamic properties involved in the movement of articulators (Saltzman 1986). As Pierrehumbert (1980) states, it is probably true that a good theory of interpolation depends on a better understanding of motor control, but while it is acknowledged that the trajectory shape in the acoustic signal should reflect motor constraints involved in articulator movement, this will be outside the purview of this dissertation. The investigation of F2 trajectories that follows will focus on describing the acoustic shape of the trajectories vis-a-vis the underspecification hypothesis.

Having discussed the relevant general background, we return to the central focus of investigation, i.e. vowel allophony in Marshallese, and explain in further depth why it is an interesting case for the underspecification hypothesis.

CHAPTER 2: THE MARSHALLESE SOUND SYSTEM

Marshallese is an Austronesian language belonging to the Micronesian group. It is spoken by approximately 29,500 speakers on the Marshall Islands (Grimes 1992), located in the Pacific Ocean between Australia and Hawaii. A map of the islands is presented in Figure 2.1. There are two major dialects, Rälik and Ratak, associated with the western and eastern chain of islands, respectively.

FIGURE 2.1. THE MARSHALL ISLANDS (AFTER STANLEY 1985)



A few papers concerning the Marshallese sound system were published in the first half of this century (Carr 1945; Carr & Elbert 1945; Kroeber 1911; Matsuoka 1929). More recent studies include a study of velarization by Tsuchida (1965) and a general acoustic sketch by Ko (1962). By far the most extensive study of Marshallese phonology has been conducted by Bender (1963; 1968; 1969a; 1969b). This includes a dictionary (Abo, et al., 1976), compiled in collaboration with a number of Marshallese speakers and linguists.

While much of the theoretical discussion in this dissertation is motivated by Bender's analysis of the vowel system (presented below), the data for this study are drawn from unpublished work from a phonetic field course conducted at UCLA and individual consultation with speakers of the Rälik dialect in the Los Angeles area. Readers are also referred to studies by Maddieson (1991) and Byrd (1992) which rose out of the phonetic field course.

Specifically, this chapter will focus on Bender's (1968) proposal that the Marshallese vowels phonemically contrast only along the height dimension, and that all surface variation in vowel quality is contextually determined by the quality of the surrounding consonants. This analysis is what makes Marshallese of interest with respect to the issues of underspecification and coarticulation. The analysis, along with a sketch of the Marshallese sound system, is presented below.

2.1. CONSONANTS

The Marshallese consonantal system, presented in Table 2.1, is characterized by three places of articulation - bilabial, coronal and velar. The series labeled coronal is described by Bender as being dental. However, consultation with native speakers shows some variation within this class so that these were sometimes realized as denti-alveolars and/or alveolars. There is an oral-nasal distinction at all places of articulation, but no voicing contrast. The coronal series also includes lateral and rhotic consonants. Bender (1968) also lists three phonemic semi-consonants /j/, /w/ and /h/ in the Marshallese inventory. The symbol /ɰ/ is used instead of Bender's /h/ in this study for reasons that are explained in section 2.2.3 below. /j/ and /w/ are phonetically realized in word initial and final positions. /ɰ/ (Bender's /h/), however, is never phonetically instantiated but is motivated in the phonology. This is discussed in section 2.2.3. Each of the 22 consonants listed in Table 2.1 is reported has having a geminate counterpart.

TABLE 2.1. MARSHALLESE CONSONANTAL INVENTORY

	bilabials	*coronals*		*velars*
palatalized	pʲ	t̪ʲ		
velarized	pˠ	t̪ˠ		k
rounded				kʷ
palatalized	mʲ	n̪ʲ		
velarized	mˠ	n̪ˠ		ŋ
rounded		n̪ʷ		ŋʷ
palatalized		l̪ʲ	r̪ʲ	
velarized		l̪ˠ	r̪ˠ	
rounded		l̪ʷ	r̪ʷ	
palatalized		j		
velarized				ɰ
rounded	w			

Constrictions at the primary sites are accompanied by any of three secondary articulations - palatalization, velarization and rounding. It is not the case, however, that all places exhibit all three secondary articulations, as shown in Table 2.1. The secondary articulations are contrastive in both syllable initial and final positions. Examples are given in Table 2.2 for secondary palatalization and velarization. As will be explained in section 2.2.3, the three semi-consonants /j/, /w/ and /ɰ/ might be analyzed as the palatalized, rounded and velarized members of an otherwise featureless series.

TABLE 2.2. SECONDARY ARTICULATION CONTRASTS IN INITIAL AND FINAL POSITION

/pˠɐtˠ/	'slow'	/pˠɐtʲ/	'lower abdomen'
/tˠəpˠ/	'to pull'	/tˠəpʲ/	'type of pandamus'
/pʲɐtˠ/	'swamp'	/pʲɐtʲ/	'circumcised penis'
/tʲəpˠ/	'work shift'	/tʲəpʲ/	'to return'

In final position, the Marshallese stops are often unreleased, yet are distinctive. The stops also exhibit partial voicing in intervocalic position. Otherwise, the consonants of Marshallese are very stable. The only exception is the palatalized coronal /tʲ/ which is allophonically realized as either [tʲ], [ç] or [ç]; these alternants are in free variation.

2.2. VOWELS

Bender (1968) reports four degrees of vowel height in Marshallese - high, upper-mid, mid and low. There is some question regarding the upper-mid series. Bender (1968: 23-24) states that many of the contrasts involving the upper-mid series can be eliminated, based on alternations associated with the high and mid counterparts. Even when these contrasts are phonologically eliminated, however, there are a number of minimal pairs (albeit the frequency of such pairs is low) between the upper-mid series and the high and mid series. Some of these minimal contrasts were checked with a native-speaker who judged some of the pairs as distinct and some of the pairs as homophonous. The confusion relating to these vowels could stem from a historical process that is currently in progress. This is, of course, entirely speculative. Regardless, given the uncertain status of the upper-mid series of vowels, they will be excluded from the current study.

Phonetically, Marshallese exhibits fronted, back unrounded, back rounded and diphthongal vowels. These vowels occur on the surface in initial, medial and final positions. Medially, a length contrast can be found between short and long vowels. For the short vowels, surface vowel quality is restricted as a function of surrounding consonantal context. These restrictions are discussed in turn in the following sections.

2.2.1. MEDIAL SHORT VOWELS

Bender (1968: 19) makes the crucial observation that "there [are] severe but systematic restrictions on the occurrence of short vowels in syllables introduced and closed by consonants". These restrictions, summarized in Table 2.3, are based on the secondary articulation of the preceding and following consonants. In symmetrically palatalized environments, only front vowels occur; in symmetrically velarized environments, only back unrounded vowels occur; and in symmetrically rounded environments, only rounded vowels occur. Sample forms are presented in Table 2.4.

TABLE 2.3. RESTRICTED VOWEL DISTRIBUTION IN SYMMETRIC CONSONANTAL CONTEXTS

	Cʲ __ Cʲ	Cˠ __ Cˠ	Cʷ __ Cʷ
/HIGH/	i	ɯ	u
/MID/	e	ʌ	o
/LOW/	ɛ	a	ɔ

TABLE 2.4. EXAMPLES OF VOWELS IN SYMMETRIC SECONDARY ARTICULATION CONTEXTS

Cʲ __ Cʲ		Cˠ __ Cˠ		Cʷ __ Cʷ	
[pʲitʲ]	'tar'	[pˠɯpˠ]	'triggerfish'	[rʷurʷ]	'pick flowers'
[tʲipʲ]	'foul ball'	[tˠɯpˠ]	'reward'	[kʷukʷ]	'cook'
[pʲetʲ]	'pandamus key'	[pˠʌpˠ]	'pandamus'	[rʷorʷ]	'bark'
[tʲepʲ]	'work shift'	[tˠʌpˠ]	'to pull'	[pʷokʷ]	'wet'
[pʲɛtʲ]	'circumcised penis'	[pˠapˠ]	'fit tightly'	[rʷɔŋʷ]	'canoe part'
[tʲɛpʲ]	'cheek'	[tˠapˠ]	'foggy'	[lʷɔŋʷ]	'housefly'

In asymmetric environments, i.e. where the secondary articulation of C_1 does not equal that of C_2, the resulting vowel is said to change in quality, such that "...the phonetic facts [result] from competing consonantal influences on a less fully specified vowel" (Bender 1968; 20). Some examples are provided in Table 2.5. These vowels have been transcribed with on-glides and off-glides surrounding a neutral vowel to reflect their diphthongal character.

Based on this distributional evidence, Bender reduces the phonemic vowel inventory to three vowels - /HIGH/, /MID/, and /LOW/ - and states that the surface vowels are contextually determined (cf. Zewen 1977). Bender's analysis is primarily motivated by a desire to simplify the morphophonemic system. For example, his previous analysis of the language (Bender 1963: 63-64) required 20 rules to account for stem vowel morphophonemics associated with the possessive pronoun suffixes. By reducing the vowel system to {/HIGH/, /MID/, /LOW/}, only three rules are needed. In addition to this simplification of the morphophonemic system, however, Bender's analysis correctly makes predictions about gaps in the distribution of vowel qualities in various consonantal contexts. For example, it is never the case that the front vowels [i], [e] and [ε] will be found between two velarized consonants, nor is it ever be the case that [ɯ], [ʌ] and [a] are found between two palatalized consonants. His analysis also precludes front vowels such as [i], or diphthongs with high off-glides such as [ɯⁱ], from appearing before velar stops given that there is no /kʲ/ in the phonemic inventory.

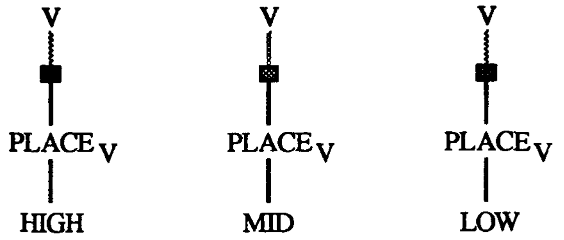
TABLE 2.5. RESTRICTED VOWEL DISTRIBUTION IN ASYMMETRIC SECONDARY ARTICULATION CONTEXTS

Cʲ _ Cˠ		Cˠ _ Cʲ	
[lʲⁱɨᵚmˠ]	'murky water'	[kˠᵚɨⁱlʲ]	'skin'
[lʲᵉəᶺtˠ]	'well-sifted'	[pˠᶺəᵉlʲ]	'to lead'
[lʲᵋɐᵃŋˠ]	'sky'	[tˠᵃɐᵋpʲ]	'frame'
Cʷ _ Cˠ		Cˠ _ Cʷ	
[kʷᵘɨᵚrˠ]	'a fish'	[rˠᵚɨᵘkʷ]	'yaws'
[kʷᵒəᶺpˠ]	'orderly'	[pˠᶺəᵒkʷ]	'wet'
[kʷᵓɐᵃlˠ]	'wash'	[lˠᵃɐᵓkʷ]	'the last'

2.2.1.1. A PHONETIC UNDERSPECIFICATION ACCOUNT

Assuming Bender's analysis to be true, then vowel allophony in Marshallese can be interpreted within the underspecification paradigm as follows: (i) underlyingly, the vowels of Marshallese are unspecified for the feature [±BACK]; (ii) the vowels remain unspecified for [±BACK] into the phonetic component; (iii) surface variation is derived by interpolation between C_1 and C_2 targets.

FIGURE 2.2. UNDERLYING REPRESENTATION OF PHONEMIC HEIGHT CONTRASTS



Within the underspecification paradigm presented in Chapter I, the observation that the phonemic vowels of Marshallese contrast uniquely along the height dimension can be represented as illustrated in Figure 2.2; the underlying vowels are specified only for height and retain no specification on the front/back dimension. Only relevant structure is shown. A nonlinear representational model which differentiates a consonantal and vocalic place node, similar to that proposed by Clements (1991), is adopted, although it is not the case that the analysis is crucially dependent on Clements' theory. While the issues associated with distinctive feature theory and feature geometry are important ones, the choice of features defined below is not crucial to the analysis at hand.

In the representation of consonants, it is assumed that secondary articulation is defined in terms of a vocalic place node (PLACE$_V$) that dominates a feature which defines the relevant secondary constriction site. Velarized consonants are defined by the feature [VELAR], and palatalized consonants are defined by the feature [PALATAL]. This is illustrated in Figure 2.3 for the phonemic bilabial contrasts. The examples presented in the remainder of this chapter will focus on the palatalized and velarized cases, although the same generalizations can be extended to the rounded cases.

FIGURE 2.3. UNDERLYING REPRESENTATION OF SECONDARY ARTICULATION CONTRASTS

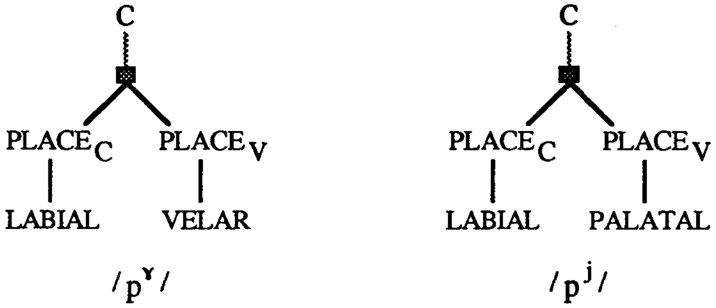
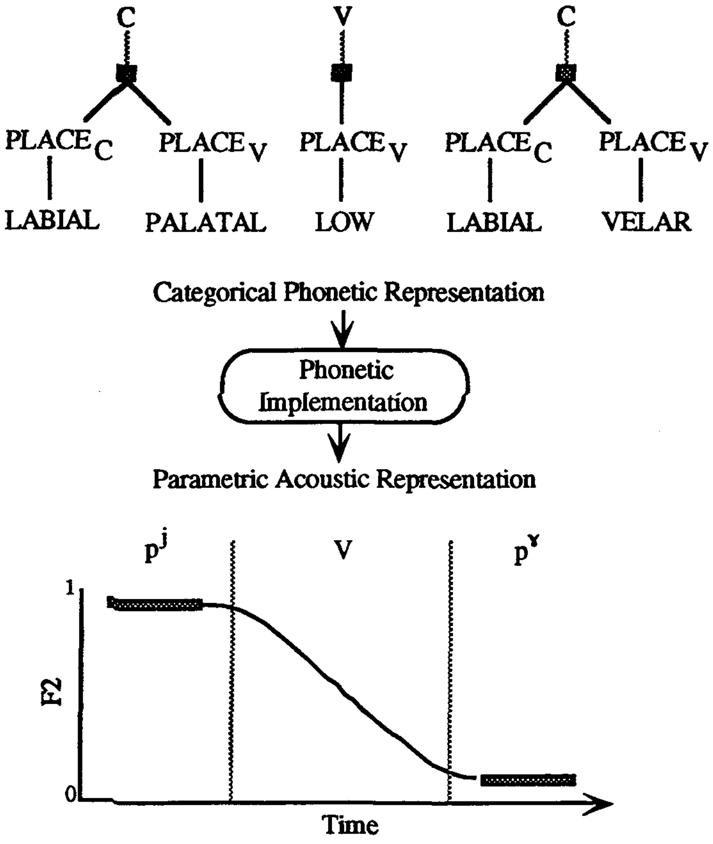


FIGURE 2.4. PROPOSED DERIVATION OF SHORT VOWELS IN CVC SYLLABLES



The features [PALATAL] and [VELAR] are assumed to define the contrast between an anterior secondary constriction site in the palatal region and a posterior secondary constriction site in the velar region, and may be interpreted as formally equivalent to frontness ([-BACK]) and backness ([+BACK]), respectively. This is a departure from the more ecumenical use of [±BACK] and is meant to reinforce the claim that a front/back contrast is not defined in the phonemic vowel matrix, a point that is made less clear when the traditional feature [±BACK] is used. Otherwise, the choice of features is not crucial for the analysis; i.e., the same results apply regardless of the particular features that are chosen to represent variation along the front/back parameter.

Focusing initially on medial short vowels in CVC contexts, consider the proposal that these vowels *remain* unspecified for frontness/backness when they leave the phonological component so that surface variation is derived by phonetic implementation. Assuming that (i) F2 correlates with backness and (ii) that target values are assigned from feature values, Marshallese vowel allophony can acoustically be modeled by attributing an F1 target to the vowel, corresponding to the phonological height specification. F2, however, is not assigned a target value associated with backness since the vowels lack any such phonological specification. Instead, F2 is determined by the values associated with the consonants' secondary articulations and the interpolation function governing the trajectory from C_1 to C_2. This is illustrated in Figure 2.4.

2.2.1.2. PREDICTIONS

Assuming a smooth interpolation function, the F2 trajectories summarized in Figure 2.5 are predicted. In symmetric environments, we would expect a level F2 trajectory in a frequency range determined by the adjacent consonants. In asymmetric environments, we would expect dynamic F2 trajectories which would lack any steady states or inflection points, otherwise indicative of an F2 target.

FIGURE 2.5. PREDICTED F2 TRAJECTORIES

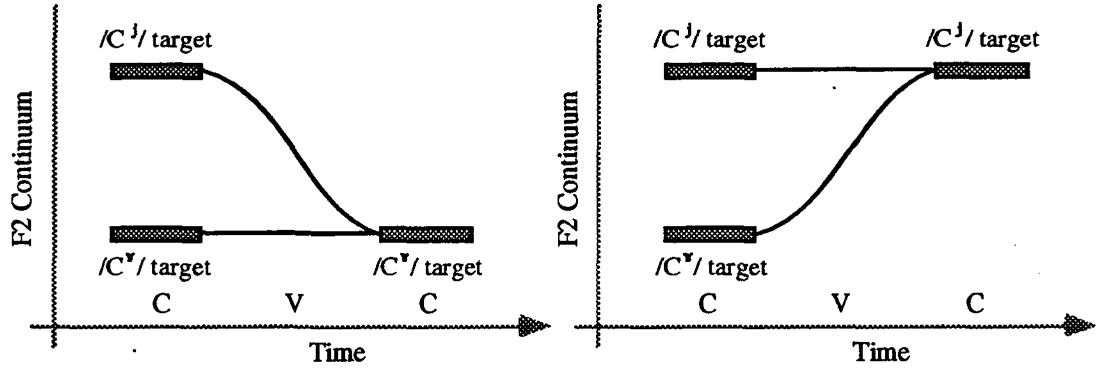


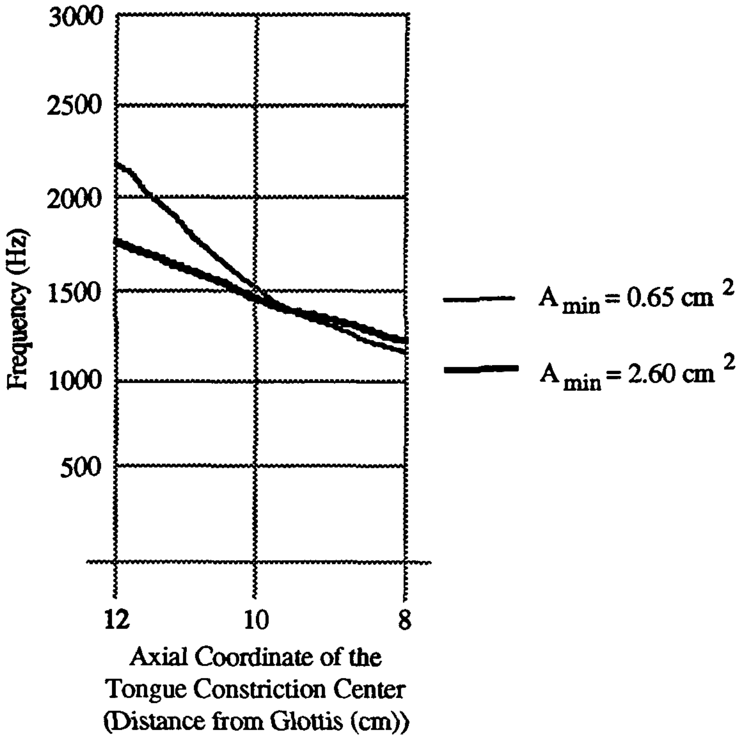
TABLE 2.6. PREDICTIONS MADE BY THE UNDERSPECIFICATION ACCOUNT

	Yes *[+VOWEL TARGET]*	*No* *[-VOWEL TARGET]*
a.	$F2 \neq f(C_1 \times C_2)$	$F2 = f(C_1 \times C_2)$
b.	$F2 = f(V)$	$F2 \neq f(V)$
c.	~ C-to-C coarticulation	C-to-C coarticulation
d.	C-to-V coarticulation	~ C-to-V coarticulation

Stated another way, we could ask: is there a vocalic F2 target? Again, different predictions are made depending on whether the answer to this question is yes or no. These are summarized in Table 2.6. If the vowels lack a F2 target associated with the front/back parameter, then we should observe variation in F2 only as a function of consonantal categories (2.6a) - an observation that should not obtain if there is a vocalic F2 target. If there is a target, then we should be able to identify a consistent F2 target (possibly a central value) associated with the syllabic nucleus (2.6b). On the other hand, acoustic theory (Fant 1960) predicts that there will be some variation in F2 with variation in tongue body height. Consider the adaptation from Fant's (1960) nomograms illustrated in Figure 2.5. The curves represent the F2 patterns predicted by his model with a narrow constriction of 0.65 cm^2 (estimating high vowels) and a more open constriction of 2.6 cm^2 (estimating a more open vowel) based on the resonant characteristics of an unrounded oral cavity. If we assume that the vowels of Marshallese are produced between the palatal and velar constriction sites, estimated as the region between 12 and 8 cm from the glottis, then we can expect to find variation in F2 corresponding to changes in constriction size alone. Fant's model predicts that this variation will be greater in magnitude in the symmetric palatalized contexts than in the velarized contexts. We should also expect to find a change in the direction of the effect depending on context. The effect is an increase in F2 as the constriction is narrowed in the palatalized context (see also Stevens & House 1955). As we move further back in the mouth, however, Fant's model predicts a slight decrease in F2 when the constriction is narrow. Precise quantitative calculations of predicted F2 variation as a function of constriction size are not attempted here. However, the qualitative differences illustrated in Figure 2.6 offer some basis on which to distinguish variation in F2 associated with variation in cross-sectional area from that associated with front/back variation.

Returning the predictions in Table 2.6, it is also the case that coarticulation can serve as a diagnostic for underspecification. If a vocalic target is absent, we should find strong consonant-to-consonant coarticulation (Table 2.6c). It is true that this prediction does not necessarily follow since the extent of consonantal influence may be limited in duration. However, the converse is not true; if strong consonant-to-consonant coarticulation is found, then it is a strong argument against a vocalic target. On the other hand, if a vocalic target is present, then we would expect that target to block or inhibit any such coarticulation. In a similar vein, if a vocalic target is present, we would expect to find significant coarticulatory interaction between consonants and vowels (2.6d). If a vocalic target is absent, then we would not expect to find such coarticulatory interactions.

FIGURE 2.6. VARIATION IN F2 ASSOCIATED WITH CONSTRICTION SIZE (AFTER FANT 1960)



2.2.2. *INITIAL AND FINAL SHORT VOWELS*

While this analysis accounts for the medial short vowels of Marshallese, there is still the question of the initial and final vowels. And while the initial and final vowels will not be examined in this study, it is worthwhile to discuss their treatment vis-a-vis the account proposed above for the medial vowels. Bender extends his analysis to cover the vowels occurring in these positions by positing underlying semi-consonants to account for the surface vowel variation arising in initial and final positions; i.e., /CVG/ and /GVC/. Since /w/ is rounded, /j/ is palatalized and /ɰ/ is velarized, the contextual influence these semi-consonants exhibit on vowel quality conforms to those exhibited by the rounded, palatalized and velarized classes of consonants. Phonetically, vowel initial words are sometimes realized with an onglide, providing some evidence for this analysis. This is not, however, consistently audible.

TABLE 2.7. EXAMPLES OF INITIAL AND FINAL VOWELS

/j V Cˠ/				/j V Cʲ/			
/jɨtˠ/	->	[itˠ]	'kindle'	/jɨtʲ/	->	[itʲ]	'I am'
/jətˠ/	->	[etˠ]	'why'	/jətʲ/	->	[etʲ]	'he/she is'
/jɐtˠ/	->	[ɛtˠ]	'name'	/jɐtʲ/	->	[ɛtʲ]	'weave'
/ɰ V Cˠ/				**/ɰ V Cʲ/**			
	->	[ɯtˠ]	'chant'	/ɰɨtʲ/	->	[ɯtʲ]	'cheer'
	->	[ʌtˠ]	'chant'	/ɰətʲ/	->	[ʌtʲ]	'horse'
	->	[atˠ]	'liver'	/ɰɐtʲ/	->	[atʲ]	'chant'

FIGURE 2.7. UNDERLYING REPRESENTATION OF SEMI-CONSONANTAL CONTRASTS

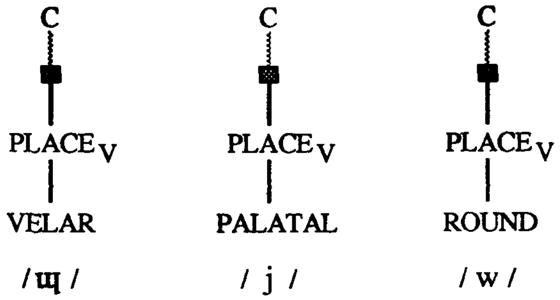
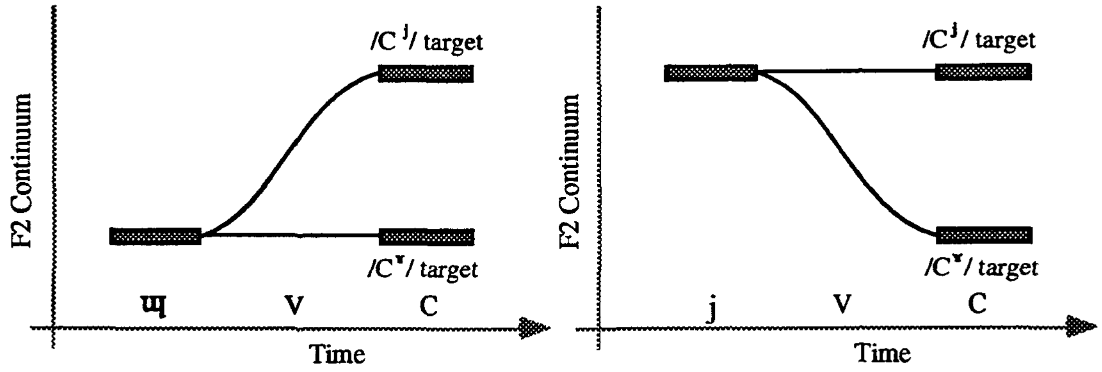


FIGURE 2.8. ACOUSTIC PARAMETRIC REPRESENTATION OF INITIAL VOWELS



Bender's analysis can be interpreted in the following terms: To begin, the semi-consonants are represented phonologically as underspecified timing slots with only a vocalic place specification in Figure 2.7. Presumably, these timing positions are interpreted by the phonology as consonantal, in so far as they constitute potential syllable onsets and offsets. Phonetically, these semi-consonants may be realized as approximants with narrowing at one of the three secondary constriction sites. The vocalic place feature associated with the semi-consonant would provide some target at the onset of the initial vowels and at the offset of the final vowels. This is illustrated in Figure 2.8 for the phonetic vowel initial cases.

The crucial question then becomes whether or not the underlying semi-consonants can be phonetically motivated. If it is the case that Bender's glides are in fact underspecified timing slots which are specified only for [VELAR], [PALATAL] or [ROUND], then these features should project targets which should in turn surface in the acoustic signal and provide phonetic evidence. In other words, if the account represented in Figure 2.6 is correct, words with the phonemic structures /jVC../ and /ɰVC../ should show the same patterns as /C^jVC/ and /$C^{ɣ}VC$/ items, respectively (cf. Table 2.6); i.e. variation in F2 temporally associated with the vowel should be a function of values at the onset and offset F2 values.

2.2.3. MEDIAL LONG VOWELS

In addition to the short vowels discussed thus far, Marshallese also exhibits a length contrast in medial position. There is a preponderance of loan words in the set of lexical items with long vowels. Some examples are provided in Table 2.8.

The medial long vowels in Marshallese are analyzed by Bender as underlying /CV_iGV_jC/, where /G/={/j/, /ɰ/, /w/}. When $V_i=V_j$, then [V:] is said to surface. When $V_i \neq V_j$, then the resulting surface variant is said to be a sequence of two short vowels, which auditorily gives the impression of a long diphthong. The situation is made more complex by the fact that the glides also contribute to surface vowel quality. Some examples of long diphthongal vowels where underlyingly $V_i \neq V_j$ are presented in Table 2.9.

Assuming that Bender's interpretation of the long vowels as underlying /...VGV.../ sequences is true, then we might posit that the input to the phonetic component is the structure represented in Figure 2.9. If this is the case, then we would expect an F2 contour like that illustrated in Figure 2.8, where the surface quality of the long vowel is derived by sequential interpolation from the initial consonant's target to the semi-consonants' target, and from the semi-consonant's target to the final consonant's target.

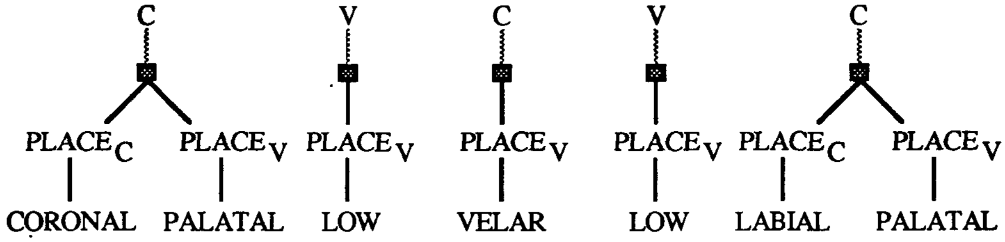
TABLE 2.8. EXAMPLES OF LENGTH CONTRASTS

SHORT		LONG (NATIVE)		LONG (LOAN)	
[pˠapˠ]	'fight tightly'	[pˠaːpˠ]	'think; believe'		
[pˠᵃɐᵋtʲ]	'lower abdomen'	[pˠaːtʲ]	'give up'		
[pˠɐtˠ]	'slow'	[pˠaːtˠ]	'smoke'		
[pʲᵋɐᵃtˠ]	'swamp'	[pʲaːtˠ]	'low tide'		
[pʲɛtʲ]	'circumcised penis'	[pʲaːtʲ]	'small oven'		
[tˠapˠ]	'foggy'	[tˠaːpˠ]	'although'		
[tˠᵃɐᵋpʲ]	'provide food'	[tˠaːpʲ]	'provide food'		
[tʲɛpʲ]	'cheek'	[tʲɛːpʲ]	'red snapper'		
[pʲⁱᶤᵚtˠ]	'tar'			[pʲɨːtˠ]	'beat'
[pʲᵉəᶺtˠ]	'pandamus key'			[pʲeːtˠ]	'bed'
[pʲⁱᶤᵚtˠ]	'challenge'			[pʲiːtʲ]	'peace'
[tʲætʲ]	'snapper fish'			[tʲaːtʲ]	'charge'
[tʲᵋaᵃtˠ]	'deep water'			[tʲaːtˠ]	'shot (of whiskey)'
[tʲⁱᶤᵚtˠ]	'to start a fire'			[tʲiːtˠ]	'sheet'

TABLE 2.9. MEDIAL LONG DIPHTHONGAL VOWELS

[kᵚᶤʲəᶺbˠ]	'spider lily'	[tʲⁱᶤʲənʲ]	'his stomach'
[tʲⁱᶤʲəᶺbˠ]	'heart of a palm'	[kˠᶺəʲɨⁱrʲ]	'compare'
[tʲᵋɐʲɨk]	'catch'	[tˠᵚᶤᵚɐᵃɤˠ]	'pandanus blossom'
[ɯᵃɐᵚəᶺɯ]	'swim'	[tˠᵚəᵚᶤᵚɯ]	'mackerel'

FIGURE 2.9. CATEGORICAL PHONETIC REPRESENTATION OF /TʲAωAPʲ/ 'RED SNAPPER'



Here, the generalization being captured is that the F2 characteristics of the medial long steady state vowels and the medial long diphthongal vowels are determined by the interaction between the secondary articulation specifications of C_1, G, and C_2. The possible set of interactions and their resulting phonetic instantiations are presented in Figure 2.9, assuming that $V_i=V_j$, for a subset of the possible C_1xGxC_2 combinations. Given that the height specification remains constant across the two syllables when $V_i=V_j$, then we would expect variation in F2 as a function of the C_n and G secondary specifications. When the secondary specification is the same across the sequence, then the result is a long steady state vowel. When there is variation in the secondary specification, however, we would expect diphthongal qualities to surface, following the same patterns predicted in Figure 2.4.

In those cases where $V_i \neq V_j$, then we would also expect diphthongal movement in F1. Bender's account also leads us to expect diphthongs with contrasting transition patterns. These are illustrated in Figure 2.10. For example, the patterns /$C^{j}VG^{j}VC^{\gamma}$/ and /$C^{\gamma}VG^{j}VC^{j}$/ should exhibit the same range of F2 movement but with later versus earlier lowering.

A phonetic underspecification account of vowel allophony in Marshallese has been proposed along with the predictions made by such an account. It remains, then, to establish whether or not these predictions obtain in the acoustic signal.

FIGURE 2.10. ACOUSTIC PARAMETRIC REPRESENTATIONS OF THE LONG VOWELS IN SYMMETRIC CONTEXTS

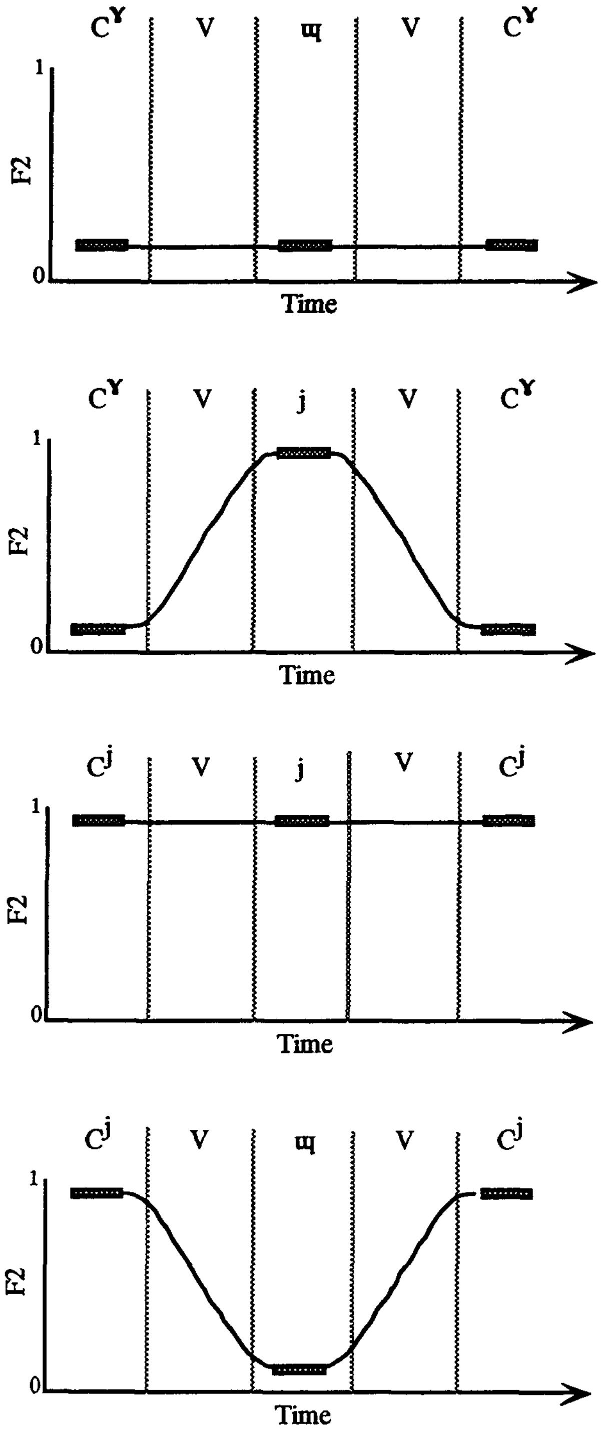
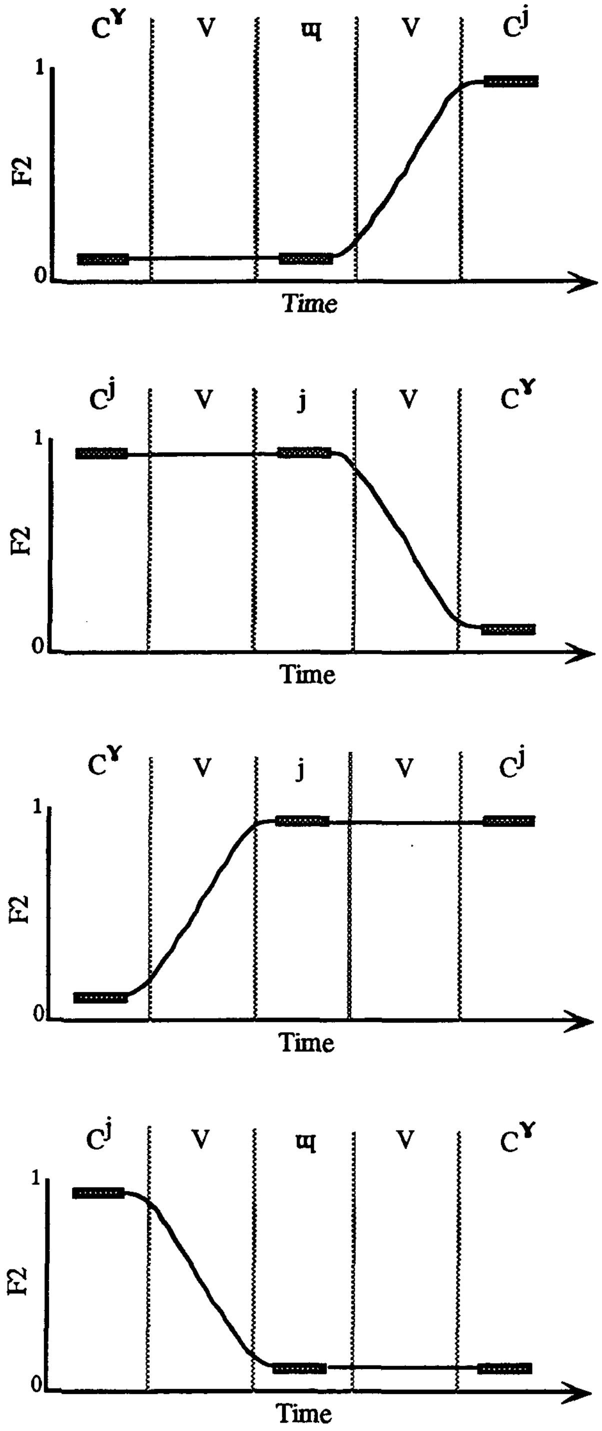


FIGURE 2.11. ACOUSTIC PARAMETRIC REPRESENTATIONS OF THE LONG VOWELS IN ASYMMETRIC CONTEXTS



Assuming that the underspecification along the front/back parameter persists into the phonetic component, then the surface allophones of Marshallese can be theoretically derived by interpolating between the C_1 and C_2 targets across a partially targetless vowel in C_1VC_2 sequences. To test the predictions made by such an account, an acoustic study was conducted. The study was designed with the following question in mind: Is there a vocalic F2 target? Certain predictions are made depending on whether or not an F2 target is present in the vowel in C_1VC_2 contexts. These were discussed in Chapter II and are reiterated here:

TABLE 3.1. PREDICTIONS IN /CVC/ CONTEXTS

	Yes *[+VOWEL TARGET]*	*No* *[-VOWEL TARGET]*
a.	$F2 \neq f(C_1 \times C_2)$	$F2 = f(C_1 \times C_2)$
b.	$F2 = f(\text{Vowel})$	$F2 \neq f(\text{Vowel})$
c.	~ C-to-C coarticulation	C-to-C coarticulation
d.	C-to-V coarticulation	~ C-to-V coarticulation

3.1. MATERIALS

The speech data for the study were collected from four native speakers of the Ralik dialect, two males (QJ, TR) and two females (DY, JG). All four speakers were born on the Marshall Islands and were raised with Marshallese as their native language. Three of the four speakers were bilingual, English being their second language. The monolingual speaker, JG, was older (50's) than the bilingual speakers (20's-30's).

A word list of /C_1VC_2/ tokens was compiled by searching lexical items in a Marshallese dictionary (Abo, et al. 1976). /V/ ranged over the posited three underlying vowel categories {/HIGH/, /MID/, /LOW/} and /C_n/ ranged over the phonemic stops {/pʲ/, /pˠ/, /tʲ/, /tˠ/}. Secondary rounding was excluded in the study. Since rounding has an effect on F2, it would have been difficult to tease out the rounding effects on F2 from those associated with tongue body configurations. The word list, presented in Table 3.2, was subsequently reviewed with the speakers to insure familiarity with the lexical items. Unfamiliar items were excluded.

The lexical search resulted in some gaps in the paradigm, and although these gaps could have been filled in by using nonsense /C_1VC_2/ tokens, non-lexical items were excluded to avoid any effects associated with this distinction. There was a sufficient set of contrasts for reliable statistical comparisons.

TABLE 3.2. /CVC/ WORD LIST

	pˠ__pˠ	pˠ__pʲ	pˠ__tˠ	pˠ__tʲ
/ɨ/	/pˠɨpˠ/ 'black triggerfish'	Ø	Ø	/pˠɨtʲ/ 'lineage, tribe'
/ə/	/pˠəpˠ/ 'pandanus'	Ø	/pˠətˠ/ 'disobedient'	/pˠətʲ/ 'swollen corpse'
/ɐ/	/pˠɐpˠ/ 'fit tightly'	Ø	/pˠɐtˠ/ 'slow'	/pˠɐtʲ/ 'lower abdomen'
	pʲ__pˠ	pʲ__pʲ	pʲ__tˠ	pʲ__tʲ
/ɨ/	Ø	Ø	/pʲɨtˠ/ 'shrink, dry'	/pʲɨtʲ/ 'tar, airfield'
/ə/	Ø	Ø	/pʲətˠ/ 'challenge'	/pʲətʲ/ 'pandamus key'
/ɐ/	Ø	/pʲɐpʲ/ 'coconut frond'	/pʲɐtˠ/ 'swamp'	/pʲɐtʲ/ 'circumcised penis'
	tˠ__pˠ	tˠ__pʲ	tˠ__tˠ	tˠ__tʲ
/ɨ/	Ø	/tˠɨpʲ/ 'celebration'	Ø	Ø
/ə/	/tˠəpˠ/ 'to pull'	/tˠəpʲ/ 'type of pandamus'	Ø	Ø
/ɐ/	/tˠɐpˠ/ "foggy'	/tˠɐpʲ/ 'fit tightly'	Ø	Ø
	tʲ__pˠ	tʲ__pʲ	tʲ__tˠ	tʲ__tʲ
/ɨ/	/tʲɨpˠ/ 'swell up, rise'	/tʲɨpʲ/ 'foul ball (baseball)'	/tʲɨtˠ/ 'to start a fire'	Ø
/ə/	/tʲəpˠ/ 'to return'	/tʲəpʲ/ 'work shift'	/tʲətˠ/ 'few, some'	Ø
/ɐ/	Ø	/tʲɐpʲ/ 'cheek'	/tʲɐtˠ/ 'deep water'	/tʲɐtʲ/ 'snapper fish'

Each token was placed in the carrier phrase [nã:n in etʲ C_1VC_2] 'this is a C_1VC_2', so that each vowel was stressed and in sentence final position. The speakers were instructed to read from the word list in a casual style. Each speaker provided 10 repetitions. One of the consultants was recorded in the sound-treated facilities at the UCLA Phonetics Laboratory, using a Tascam 122MXII Cassette-Recorder, a Symetrix SX-202 microphone pre-amplifier and a unidirectional Sennhauser microphone. The remaining three speakers were recorded in a quiet field environment, using a Marantz PMD340 Cassette-Recorder and a unidirectional Sony microphone.

3.2. PROCEDURE

The recorded speech was 16-bit digitized at a sampling rate of 10 kHz using the Kay Elemetrics CSL package. The vowel in each C_1VC_2 token was then segmented using time-aligned waveform and wideband spectrographic displays. Segmentation decisions were based on amplitude change and signal characteristics in the waveform display as well as F2 onset and offset in the spectrograms. The vowels were subsequently submitted to a pitch-synchronous, auto-correlation LPC procedure. The male voices were analyzed with a 12th-order filter; the female voices were analyzed with a 10th-order filter. The results of each LPC analysis was overlaid on a spectrographic display of the respective vowel for verification and error-checking.

In instances where the LPC analysis mistracked or failed to track the frequency components at a given glottal pulse, the missing values were calculated by interpolating between the nearest values. In a few cases where the LPC analysis provided gross errors over more than 3 pitch periods, the formant values were estimated from the spectrographic display using cursor-based measurements. Overall duration for each vowel was calculated by taking the difference in absolute time between the initial and final pitch periods.

3.3. STATISTICAL DESIGN I

To assess which, if any, of the predictions obtain, the data were initially submitted to multivariate analysis of variance tests (MANOVA). MANOVA is an extension of the standard analysis of variance technique designed to test multiple dependent variables and any correlation between these variables. Within the parameters of the current study, MANOVA permits us to ask if there is any significant variation in vowel quality, defined as a matrix of [F1 x F2], as opposed to any variation in F1 independent of F2 and vice versa. The model includes calculation of a regression coefficient matrix where each column in this matrix is a vector of coefficients corresponding to each of k dependent variables and each row in the matrix contains the coefficients associated with each of m independent variables. The linear model is then calculated using the product of an $[n \times m]$ matrix of n observations on the m independent variables with the regression matrix:

TABLE 3.3. MULTIVARIATE MODEL (CRUM 1986)

$$y = xr + e$$

$y = n$ x k matrix of observed values of k dependent variables
$x = n$ x m matrix of n observations on the m independent variables
$r = m$ x k matrix of regression coefficients
$e = n$ x k matrix of the n random errors

Sums of squares are partitioned in terms of [k x k] matrices of sums of squares and their cross products. Since matrices cannot be divided, the $E^{-1}H$ matrix is used to test for significance, where H is the model matrix and E is the error matrix.

Three MANOVA tests were submitted for each speaker. Each test involved [F1 x F2] at one of three time points T_n, where n={onset, mid, offset}. The formant frequency measures at T_{onset} and T_{offset} represent the initial and final values. T_{mid} was defined as a percentage (0.5) of overall duration. The formant frequency values at that point were then calculated by interpolating between the nearest real-time values. Variance at each time point was tested against the independent variables and interactions listed in Table 3.4.

TABLE 3.4. INDEPENDENT VARIABLES AND INTERACTIONS

MAIN EFFECT	*DESCRIPTION*	*LEVELS*
C1P	C_1 Primary articulation	bilabial : alveolar
C2P	C_2 Primary articulation	bilabial : alveolar
C1S	C_1 Secondary articulation	palatalized : velarized
C2S	C_2 Secondary articulation	palatalized : velarized
VOW	Vowel	high : mid : low

INTERACTIONS

C1P x C1S
C2P x C2S
C1P x C2P
C1S x C2S
C1P x C1S x C2P x C2S

C1P x C1S x VOW
C2P x C2S x VOW
C1P x C2P x VOW
C1S x C2S x VOW
C1P x C1S x VOW x C2P x C2S

Based on the results of the Manova tests, F1 and F2 were subsequently submitted to analysis of variance (ANOVA) tests to assess which of the two dependent factors was responsible for the variation in vowel quality. The design of the ANOVA tests included models for each speaker based on the independent variables and interactions listed in Table 3.4. Given the presence of missing cells in the model, Type III sums of squares were used to calculate F-ratios and probability scores. For the pooled data, SPEAKER(DY:JG:QJ:TR) was added as a random independent variable and a repeated measures design was used. This provided control over individuals between experimental units. The computational method used to implement the repeated measures design involved the use of the error term from the [SPEAKER x VARIABLE] interaction in the test for [VARIABLE] (Winer 1971).

3.4. RESULTS

The results of the MANOVA tests for vowel quality at T_{mid} for each speaker are summarized in Table 3.5. Only main effects are listed. The F-statistic is based on Wilks criterion, which is a likelihood ratio defined as |*Error SS*| / |*Model SS - Error SS*| (Wilks 1932; Crum 1986). The results show significant variation in vowel quality as a function of all the consonantal and vocalic categories defined in the design. In general, secondary articulation and vowel category exhibited the highest F-ratios.

TABLE 3.5. SUMMARY OF MANOVA RESULTS AT THE VOWEL MIDPOINT

T_{MID}

SPKR	*INDEPENDENT FACTOR*	*DEGREES OF FREEDOM*	*PARTIAL CORRELATION*	*F STATISTIC*	*p > F (WILKS λ)*
DY	Vowel	4, 520	-0.090395	286.378	0.0
	C_1 Primary	2, 260		55.519	0.0001
	C_2 Primary	2, 260		28.820	0.0001
	C_1 Secondary	2, 260		1401.639	0.0
	C_2 Secondary	2, 260		411.959	0.0
JG	Vowel	4, 520	0.268374	192.240	0.0
	C_1 Primary	2, 260		177.342	0.0001
	C_2 Primary	2, 260		106.001	0.0001
	C_1 Secondary	2, 260		817.557	0.0
	C_2 Secondary	2, 260		760.619	0.0
QJ	Vowel	4, 520	-0.026032	420.438	0.0
	C_1 Primary	2, 260		80.234	0.0001
	C_2 Primary	2, 260		88.206	0.0001
	C_1 Secondary	2, 260		325.643	0.0001
	C_2 Secondary	2, 260		411.745	0.0
TR	Vowel	4, 520	-0.215219	308.782	0.0
	C_1 Primary	2, 260		66.342	0.0001
	C_2 Primary	2, 260		82.666	0.0
	C_1 Secondary	2, 260		234.605	0.0001
	C_2 Secondary	2, 260		265.080	0.00001

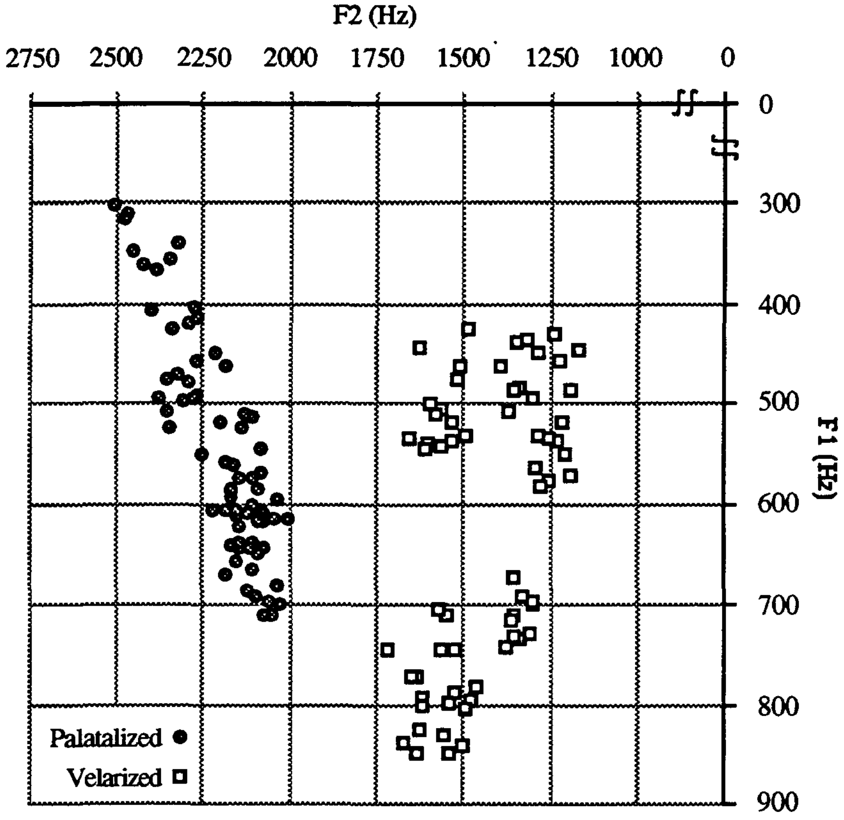
3.4.1. CATEGORICAL EFFECTS AT THE VOWEL MIDPOINT

3.4.1.1. CONSONANTAL EFFECTS

To identify the extent to which each of the dependent variables, F1 and/or F2, served as the primary parameter of variation responsible for the significant effects summarized in Table 3.4, F1 and F2 were independently examined for each speaker.

To begin, consider the front-back variation in symmetric consonantal environments reported by Bender (1968), as illustrated in Figure 3.1. The values plotted in this linear [F2 x F1] vowel space were taken at the vowel midpoint in both symmetrically velarized and palatalized contexts for one female speaker. A distinct, non-overlapping distribution associated with the secondary articulation types is observed; all the tokens in velarized contexts exhibit F2>2000 Hz and all those in the palatalized contexts exhibit F2<1750 Hz. A similar trend was exhibited by the other speakers as well.

FIGURE 3.1. VARIATION IN SYMMETRIC CONSONANTAL SECONDARY ARTICULATION CONTEXTS (DY)



The repeated measures ANOVA test found the variation in both F1 (C1S: $F_{1,1158}$=23.00, p<0.0172; C2S: $F_{1,1158}$=19.01, p<0.0223) and F2 (C1S: $F_{1,1158}$=21.97, p<0.0184; C2S: $F_{1,1158}$=23.47, p<0.0168) to be statistically significant as a function of the secondary consonantal articulations. The mean values and standard deviations for F1 and F2 associated with the secondary articulation types are presented in Figure 3.2. The effects are very consistent for both F1 and F2; the vowels exhibit a lower F1 and a higher F2 in palatalized contexts as compared to velarized contexts. However, the overall variance in F2 associated with secondary articulations is much greater than in F1 as shown by the standard deviation bars. F2 also exhibits much greater sensitivity to palatalization and velarization. In Figure 3.2, this can be seen in the greater difference between the means associated with the vowels in velarized and palatalized contexts for F2.

The variation associated with the interaction between C1S and C2S is illustrated in Figure 3.3. F2, measured at the vowel midpoint, is plotted as a function of the four possible [C1S x C2S] combinations. Interestingly, the mean values associated with the [VELAR x PALATAL] and [PALATAL x VELAR] interactions differ, suggesting that the effects of C_1 and C_2 at the observed midpoint are asymmetric. This asymmetry is explored further in the discussion of consonant-to-consonant coarticulation (section 3.4.2.1) as well as in the discussion of the regression results (section 3.6.2).

FIGURE 3.2. MEANS AND STANDARD DEVIATIONS OF F1 & F2 AT THE VOWEL MIDPOINT AS A FUNCTION OF CONSONANTAL SECONDARY ARTICULATION (POOLED DATA)

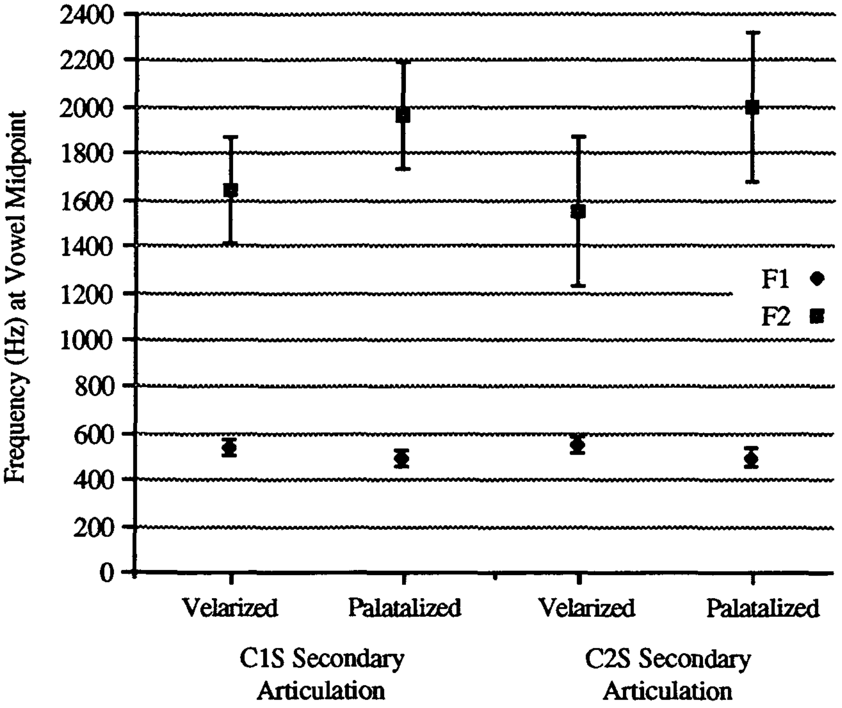


FIGURE 3.3. MEANS AND STANDARD DEVIATIONS OF F2 AT THE VOWEL MIDPOINT AS A FUNCTION OF C1S X C2S (POOLED DATA)

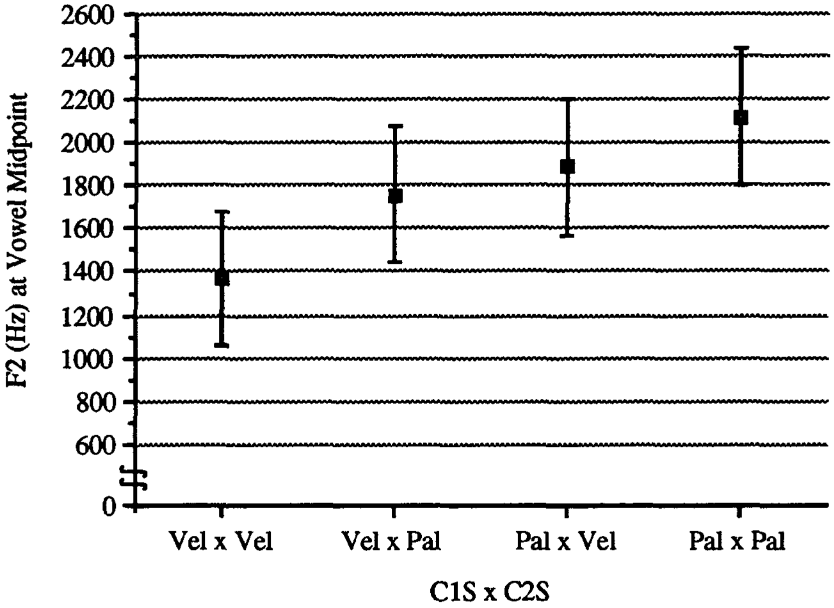
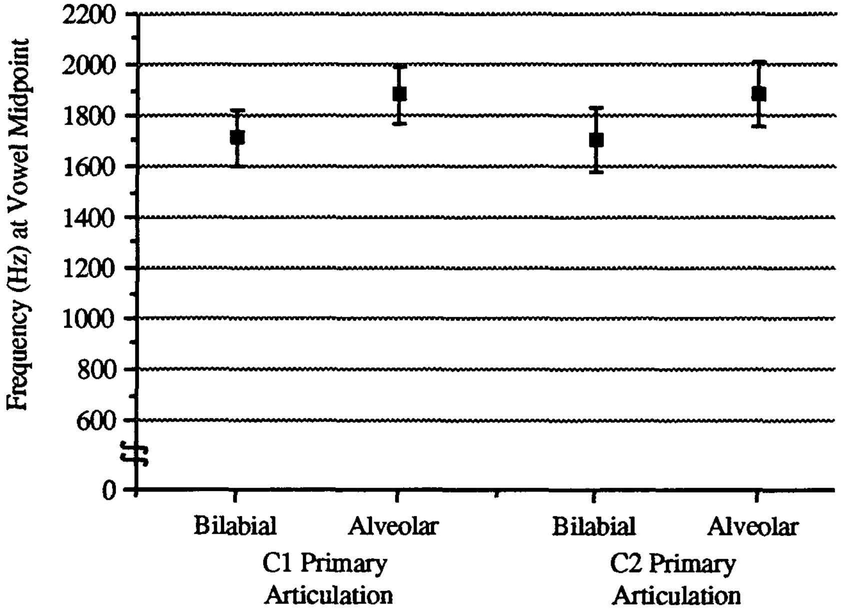


FIGURE 3.4. MEANS AND STANDARD DEVIATIONS OF F2 AT THE VOWEL MIDPOINT AS A FUNCTION OF PRIMARY PLACE OF ARTICULATION (POOLED DATA)

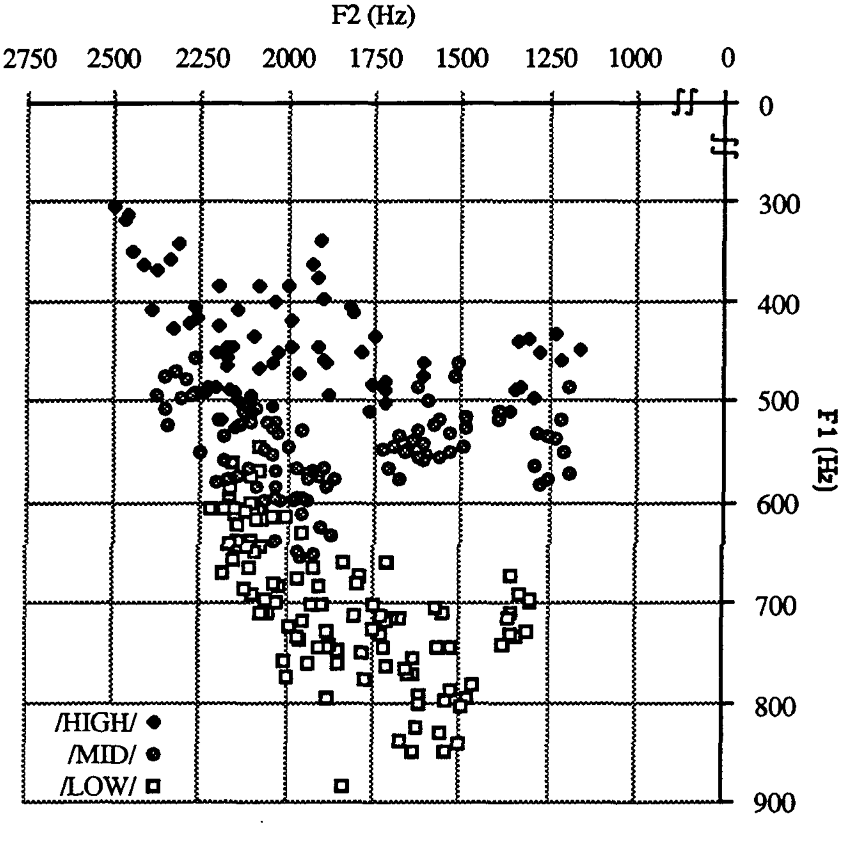


3.4.1.2. VOCALIC EFFECTS

The division of the vowel space based on the proposed intrinsic height contrasts is represented in a linear [F2 x F1] acoustic vowel space in Figure 3.5. The values represented in this plot are those taken at the vowel midpoint for one female speaker. The remaining three speakers exhibited similar trends.

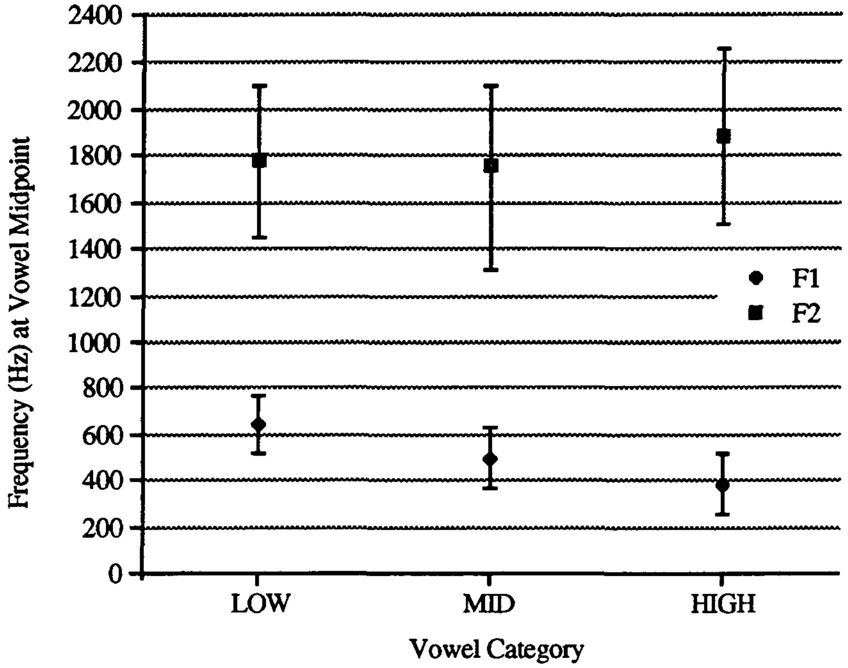
The means and standard deviations for F1 and F2 at the vowel midpoint for the pooled data are plotted in Figure 3.6. Variation in F1 is consistent with expected trends and was found to be highly significant (VOW: $F_{2,1157}=964.94$, $p<0.0001$). Crucially, the magnitude of the difference in the F1 means associated with vowel categories is greater than that observed in the F1 means associated with palatalization and velarization (cf. Figure 3.2).

FIGURE 3.5. ACOUSTIC REALIZATION OF THE INTRINSIC HEIGHT CONTRASTS (DY)



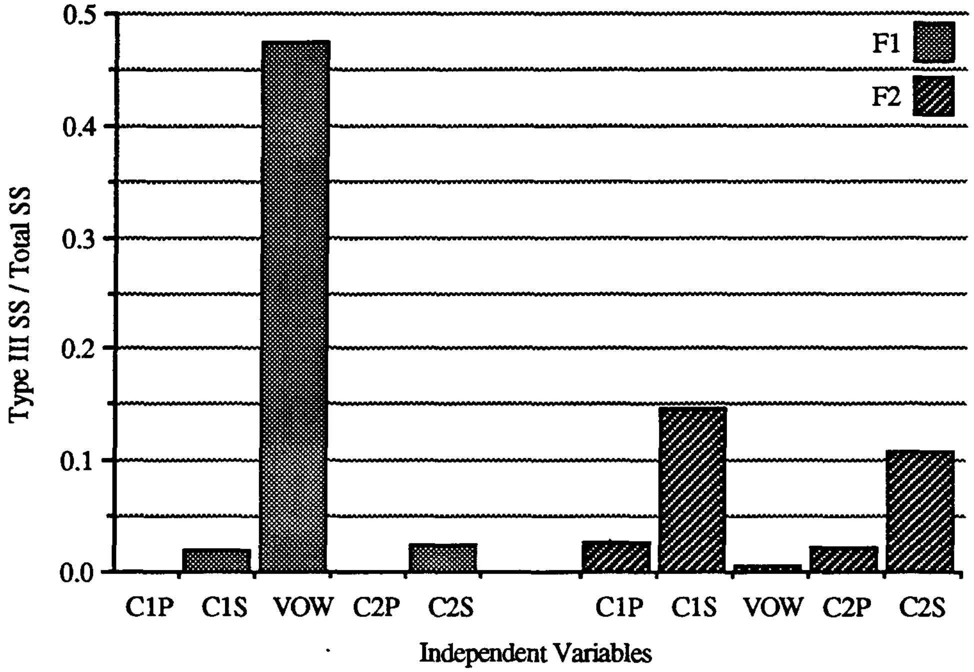
The individual speakers also showed some variation in F2 associated with vowel height. This trend is reflected in the pooled data as well. In particular, the high vowels exhibit a higher mean F2 than the mid and low vowels. Overall, the variation in F2 as a function of vowel category is much weaker than that found for F1. Nevertheless, this variation was found to be statistically reliable (VOW: $F_{2,1157}=5.28$, $p<0.0476$).

FIGURE 3.6. MEANS AND STANDARD DEVIATIONS FOR F1 & F2 AT THE VOWEL MIDPOINT (POOLED DATA)



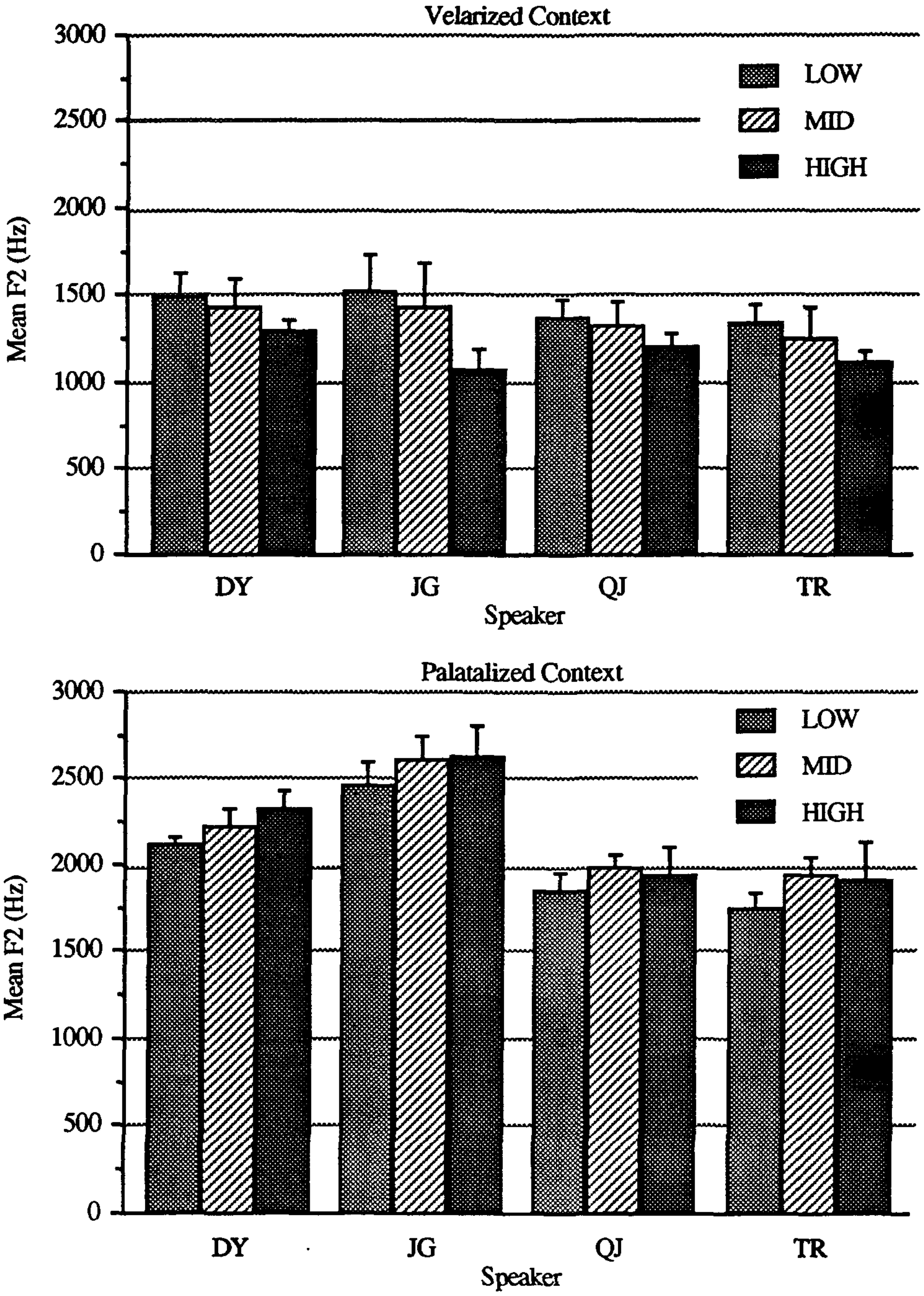
In interpreting the effect of vowel height, the relative contribution of the five independent factors to variation observed in F2 at the vowel midpoint was considered. Relative contribution was estimated by taking the ratio of the type III sums of squares with the total sums of squares in the linear model. The results are plotted in Figure 3.7. As the histogram shows, the contribution of vowel category (VOW) to F2 variation is extremely low compared to the contributions of C_1 and C_2, especially their secondary articulations. These results corroborate the greater magnitude of the differences in mean values discussed above, which showed that F2 was much more sensitive to consonantal palatalization and velarization than it was to vowel category, and to a lesser extent, primary articulation. The same ratios for F1 are also plotted for comparison. Here, the opposite trends obtain; vowel category is contributing much more than C_1 and C_2 to the variation in F1. Primary articulation was not found to have a significant effect on F1.

FIGURE 3.7. RELATIVE CONTRIBUTION OF THE INDEPENDENT VARIABLES TO THE OVERALL VARIATION IN F1 & F2 (POOLED DATA)



The comparison in Figure 3.7 suggests that the weak effect of vowel category on F2 does not necessarily constitute evidence for different vocalic F2 targets associated with variation along the front/back parameter. Instead, the effect could be attributed to the differences in constriction size alone. To better evaluate the possibility that the observed variation in F2 associated with vowel category can be attributed to differences in constriction size, the data were re-examined in the context of the predictions discussed in section 2.2.1.2 (see Figure 2.5). Recall that these predictions, based on Fant (1960), provided some criteria with which to evaluate the effects of cross-sectional area on the second formant frequency. Differences in the direction and magnitude of F2 variation were predicted as a function of both constriction size and constriction location. In the palatal region, estimated at approximately 12 cm. from the glottis, a narrow constriction produces a higher F2 than a wider constriction. When the constriction is further back in the cavity, at approximately 10 cm. from the glottis, there is very little F2 variation predicted. If the constriction site is located even further back in the mouth at approximately 8 cm. from the glottis, the second resonance is predicted to decrease slightly as the constriction becomes narrower.

FIGURE 3.8. MEAN F2 IN THE SYMMETRIC VELARIZED AND PALATALIZED CONTEXTS (INDIVIDUAL DATA)



The mean F2 values associated with each vowel category in the two consonantal contexts /C$^{\gamma}$VC$^{\gamma}$/ and /C^{j}VC^{j}/ are presented in Figure 3.8. The figures reveal that the data, while not completely in conformity with the predictions outlined above, do exhibit some trends which suggest that the variation in F2 is associated with variation in constriction size. In the velarized context, we observe a consistent trend across all speakers in which F2 decreases as the constriction becomes narrower. This trend is expected if the constriction is as far back as 8 cm from the glottis. However, the magnitude of the difference is slightly greater than expected, and there is one speaker (JG), for whom the difference is considerably greater. In the palatalized context, we find that the predicted trend is only observed in the female speakers, who exhibit higher F2 values as the constriction size becomes narrower. For the male speakers, the high vowels have lower mean F2 values than the mid vowels. While the magnitude of this difference is very small, the trend is consistent.

While the data in Figure 3.8 do not provide conclusive evidence that the observed variation in F2 can be attributed to variation in constriction size, the results do exhibit some of the characteristics that we would associate with differences in cross-sectional area. This, along with the facts illustrated in Figure 3.7, strongly suggest that the differences in F2 are being controlled by consonantal context and not by an inherent front~back specification associated with the vowel itself. Having established these points based on an examination of the data at T_{mid}, we now turn to F1 and F2 at the vowel onset and offset to test for consonant-to-consonant coarticulatory effects.

3.4.2. CATEGORICAL EFFECTS AT THE VOWEL ONSET AND OFFSET

If the vowel is not contributing an F2 target of its own, then the C_1 and C_2 F2 targets are in principle free to interact; i.e., we might expect to find consonant-to-consonant coarticulation. Coarticulatory influence is assessed by measuring variation in F2 at the vowel onset as a function of C_2, and at the vowel offset as a function of C_1. Variation at the onset corresponds to anticipatory effects while those at the offset correspond to carryover effects.

The results of the MANOVA tests for vowel quality (defined as [F1 x F2]) at T_{onset} and T_{offset} show highly significant consonant-to-consonant coarticulation for all speakers in both directions. The only exception to this generalization is the effect of C2P at the vowel onset for speaker QJ. While this effect is not significant, there is a weak trend suggested by the 0.07 probability level. These results are summarized in Tables 3.6; only the main effects are listed.

TABLE 3.6. SUMMARY OF MANOVA RESULTS AT THE VOWEL ONSET & OFFSET

ONSET

SPKR	*INDEPENDENT FACTOR*	*DEGREES OF FREEDOM*	*PARTIAL CORRELATION*	*F STATISTIC*	*$p > F$ (WILKS λ)*
DY	Vowel	4, 520	0.097275	59.007	0.0001
	C_1 Primary	2, 260		736.208	0.0
	C_2 Primary	2, 260		15.183	0.0001
	C_1 Secondary	2, 260		1967.744	0.0
	C_2 Secondary	2, 260		55.317	0.0001
JG	Vowel	4, 520	0.228343	68.177	0.0001
	C_1 Primary	2, 260		1010.344	0.0
	C_2 Primary	2, 260		11.300	0.0001
	C_1 Secondary	2, 260		2102.696	0.0
	C_2 Secondary	2, 260		141.186	0.0001
QJ	Vowel	4, 520	0.083090	100.047	0.0001
	C_1 Primary	2, 260		446.614	0.0
	C_2 Primary	2, 260		2.658	0.0720
	C_1 Secondary	2, 260		797.135	0.0
	C_2 Secondary	2, 260		36.453	0.0001
TR	Vowel	4, 520	0.009228	103.160	0.0001
	C_1 Primary	2, 260		291.430	0.0001
	C_2 Primary	2, 260		9.777	0.0001
	C_1 Secondary	2, 260		1038.630	0.0
	C_2 Secondary	2, 260		47.525	0.00001

OFFSET

SPKR	*INDEPENDENT FACTOR*	*DEGREES OF FREEDOM*	*PARTIAL CORRELATION*	*F STATISTIC*	*$p > F$ (WILKS λ)*
DY	Vowel	4, 520	0.164171	46.824	0.0001
	C_1 Primary	2, 260		6.988	0.0011
	C_2 Primary	2, 260		222.281	0.0001
	C_1 Secondary	2, 260		137.737	0.0001
	C_2 Secondary	2, 260		636.527	0.0
JG	Vowel	4, 520	0.080959	54.515	0.0001
	C_1 Primary	2, 260		6.025	0.0028
	C_2 Primary	2, 260		1165.412	0.0
	C_1 Secondary	2, 260		40.450	0.0001
	C_2 Secondary	2, 260		2484.085	0.0
QJ	Vowel	4, 520	0.043706	41.277	0.0001
	C_1 Primary	2, 260		13.468	0.0001
	C_2 Primary	2, 260		855.144	0.0
	C_1 Secondary	2, 260		3.346	0.0368
	C_2 Secondary	2, 260		824.158	0.0
TR	Vowel	4, 520	0.156362	70.325	0.0001
	C_1 Primary	2, 260		3.928	0.0209
	C_2 Primary	2, 260		498.192	0.0
	C_1 Secondary	2, 260		14.862	0.0001
	C_2 Secondary	2, 260		821.414	0.0

The data also show strong effects of vowel height on [F1x F2] at the onset and offset positions. This is true for all speakers. Given the weak evidence for a vocalic F2 target at the vowel midpoint, we hypothesized that the strong effects of vowel category at the onset and offset are primarily due to variation in F1, and they do not represent the presence of a consonant-to-vowel or vowel-to-consonant effect in F2.

3.4.2.1. CONSONANT-TO-CONSONANT COARTICULATION

Independent examination of F1 and F2 corroborate the consonant-to-consonant coarticulation effects observed in the MANOVA tests and reveal that these effects are primarily seen in F2. The data exhibit a considerable amount of consonant-to-consonant coarticulation in F2 which is statistically reliable for all speakers. This effect is primarily associated with secondary place of articulation. The F2 results are summarized in Table 3.7. The differences at the vowel onset associated with C_2, and those at the vowel offset associated with C_1, are plotted in Figure 3.9 for the pooled data as a function of their respective secondary articulations. As the figure shows, the coarticulatory effects are quite high in magnitude. If we calculate the magnitude as the difference between the mean velarized and palatalized values, then carryover coarticulation results in a magnitude shift of 232 Hz, and while anticipatory coarticulation is somewhat weaker, it is still relatively high at 173 Hz.

While the pooled data show that carryover coarticulation results in greater magnitude differences than anticipatory coarticulation, and while this trend obtains for each speaker, there is some inter-speaker variation worth noting. Interestingly, this variation seems to be associated with gender. Figure 3.10 show the mean values and standard deviations for F2 at the vowel onset and offset for each individual speaker. As illustrated, the female speakers, DY and JG, exhibit greater differences in F2 depending on consonantal context.

There are further differences in the asymmetry between carryover and anticipatory coarticulation across speakers. Consider Figure 3.11 which compares the magnitude of coarticulation in the two directions. The female speakers, DY and JG, showed a greater asymmetry between carryover and anticipatory coarticulation. The male speakers, QJ and TR, showed less asymmetry, with TR exhibiting virtually no difference. The magnitude of this asymmetry, calculated as the difference in the magnitude of the coarticulation in the anticipatory and carryover cases, is summarized in Figure 3.12.

TABLE 3.7. SUMMARY OF ANOVA RESULTS (CONSONANT-TO-CONSONANT COARTICULATION)

Spkr	*Time (direction)*	*Variable*	*F-Ratio*	*Probability > F*
DY	ONSET (ANTICIPATORY)	C2S	110.23	0.0001
		C2P	18.63	0.0001
	OFFSET (CARRYOVER)	C1S	258.26	0.0001
		C1P	12.62	0.0005
JG	ONSET (ANTICIPATORY)	C2S	159.40	0.0001
		C2P	22.16	0.0001
	OFFSET (CARRYOVER)	C1S	69.25	0.0001
		C1P	0.79	0.3750
QJ	ONSET (ANTICIPATORY)	C2S	53.25	0.0001
		C2P	0.94	0.3326
	OFFSET (CARRYOVER)	C1S	6.57	0.0109
		C1P	15.66	0.0001
TR	ONSET (ANTICIPATORY)	C2S	70.82	0.0001
		C2P	7.81	0.0056
	OFFSET (CARRYOVER)	C1S	7.30	0.0073
		C1P	7.01	0.0086

FIGURE 3.9. CONSONANT-TO-CONSONANT COARTICULATION ASSOCIATED WITH SECONDARY PLACE OF ARTICULATION (POOLED DATA)

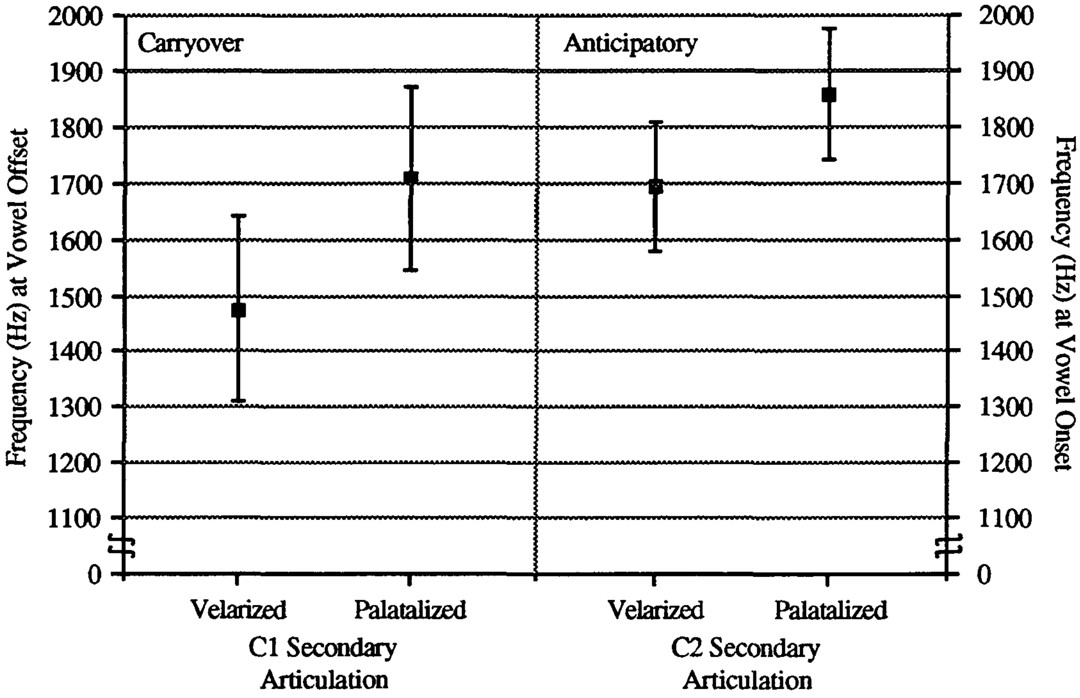


FIGURE 3.10. CONSONANT-TO-CONSONANT COARTICULATION ASSOCIATED WITH SECONDARY PLACE OF ARTICULATION (INDIVIDUAL DATA)

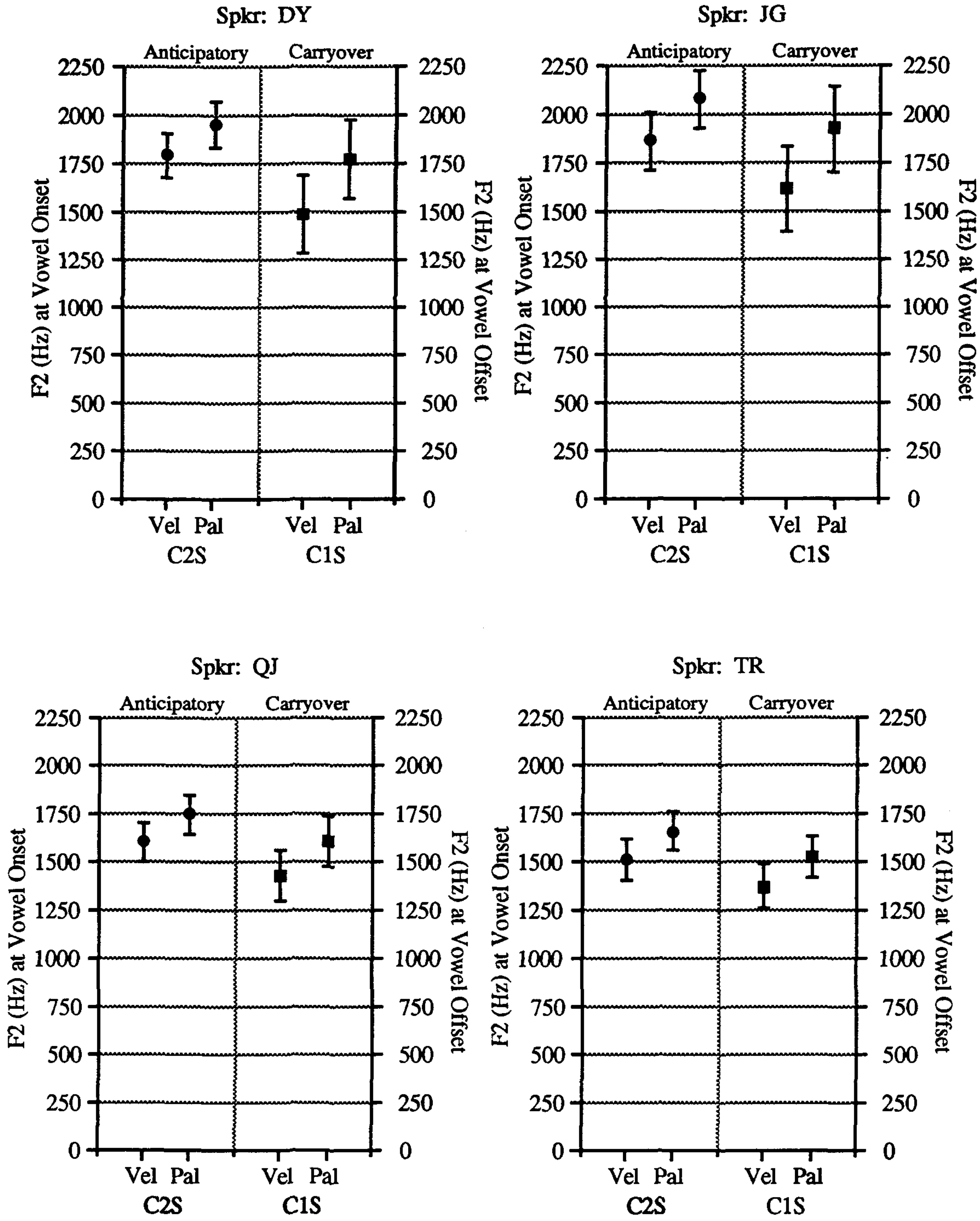


FIGURE 3.11. MAGNITUDE OF CONSONANT-TO-CONSONANT COARTICULATION (INDIVIDUAL DATA)

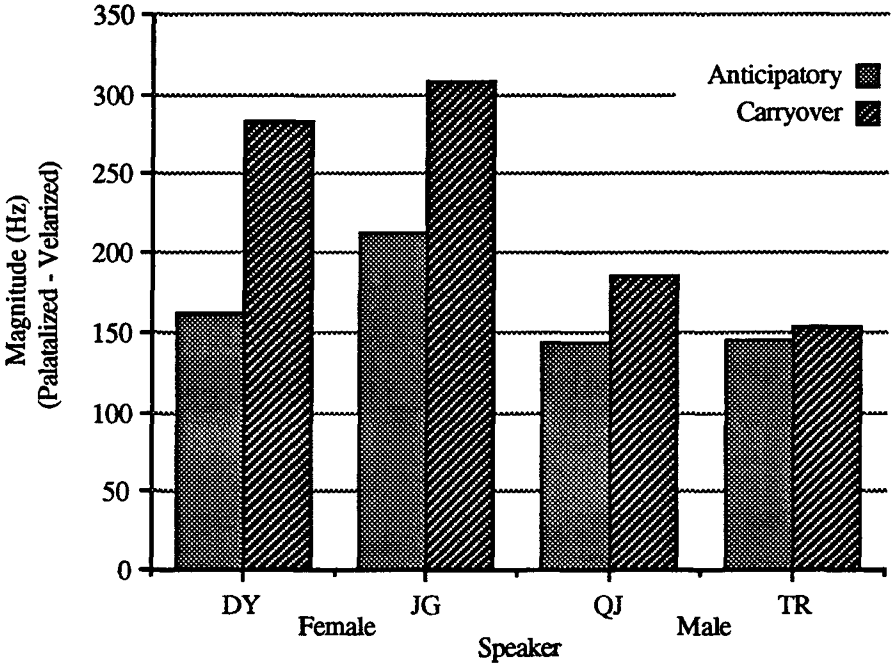
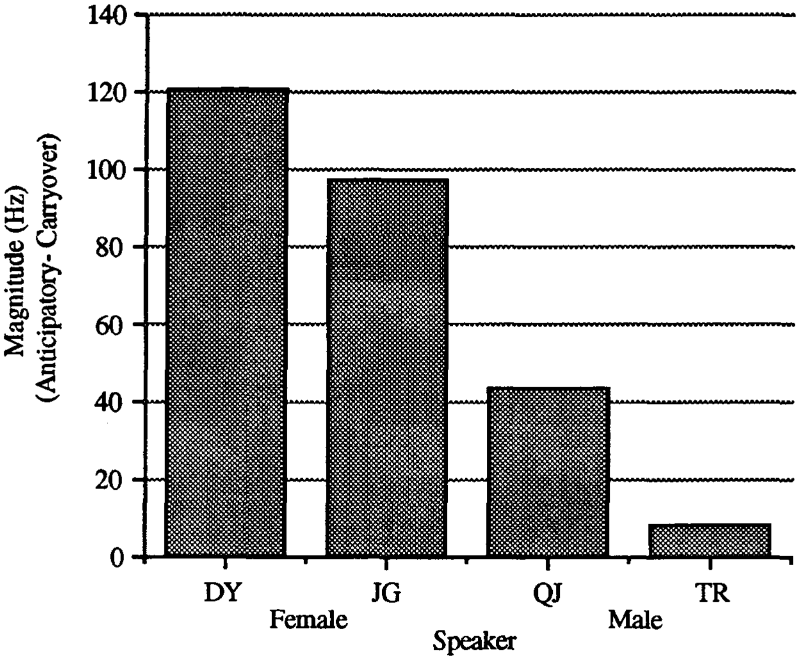


FIGURE 3.12. MAGNITUDE OF DIRECTIONAL DIFFERENCES IN CONSONANT-TO-CONSONANT COARTICULATION (INDIVIDUAL DATA)

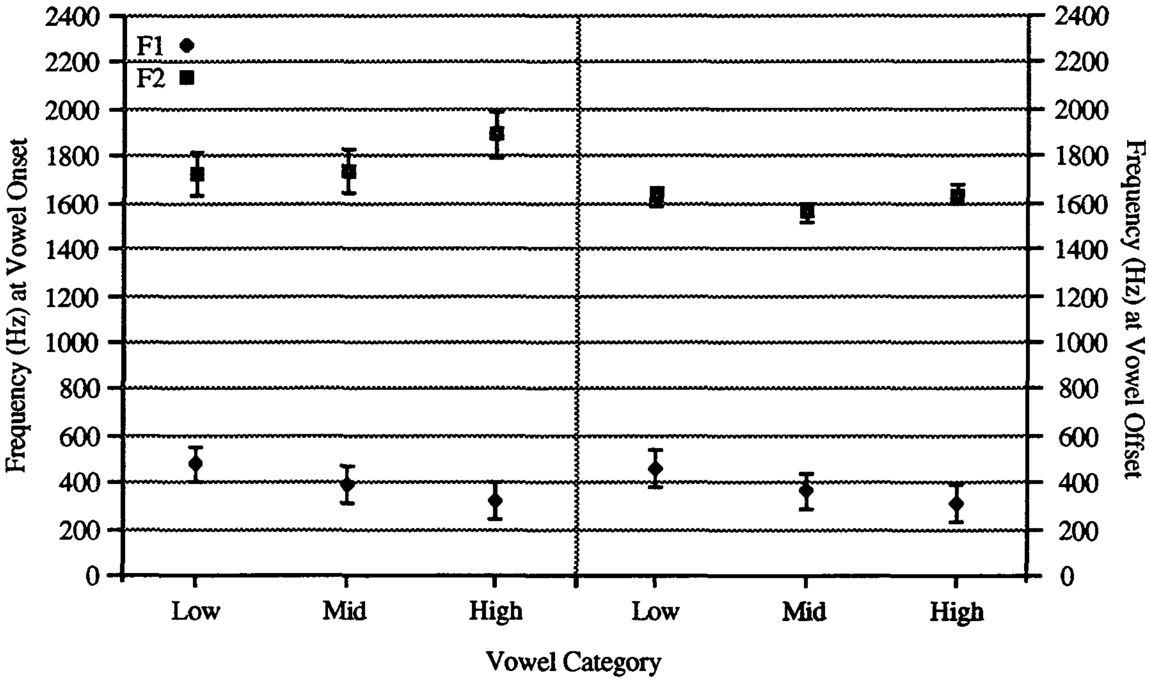


The data exhibited much more complex trends with regards to consonant-to-consonant coarticulation associated with primary articulation. In general, these effects were much weaker than those associated with secondary articulation. Moreover, there is a great deal of inter-speaker variation; while DY and TR exhibit some effects in both directions, JG only shows significant anticipatory coarticulation of primary place of articulation, while QJ only shows significant carryover coarticulation. In the pooled data, the inter-speaker variation effectively eliminated any significant carryover effects. However, the anticipatory effects were robust enough to result in a weak, but significant result at the vowel onset (C2: $F_{1,1158}=11.61$, $p \leq 0.0422$).

3.4.2.2. *CONSONANT~VOWEL COARTICULATION*

Examination of F1 and F2 at the vowel onset and offset as a function of vowel category, illustrated in Figure 3.13, supports the hypothesis that the multivariate effect of vowel category on vowel quality discussed in section 3.5.1 is primarily due to variation in F1. Vowel category was found to have a highly significant effect on F1 in both positions (VOW: $F_{2,1157}=149.39$, $p<0.0001$; VOW: $F_{2,1157}=92.78$, $p<0.0001$) for the pooled data. All speakers exhibited the same trend. The magnitude of variation, as well as the general trend in variation, is similar to that observed at the vowel midpoint (cf. Figure 3.6).

FIGURE 3.13. CONSONANT-TO-VOWEL & VOWEL-TO-CONSONANT COARTICULATION (POOLED DATA)



Variation in F2 is significant, but to a lesser extent, and only in the onset position (VOWEL: $F_{2,1157}$=21.86, p<0.0018). Examination of the F2 values at the vowel onset shows similar trends to those observed at the vowel midpoint (cf. Figure 3.6); the /HIGH/ vowel exhibits a higher F2 as compared to the /MID/ and /LOW/ vowels. However, this variation is very small in magnitude and again, is not inconsistent with the type of variation we would expect based on differences associated with vowel height. At the vowel offset, we see very little variation as a function of vowel height.

3.4.2.3. CONSONANTAL TARGETS

The MANOVA tests found highly significant effects of C_1 at the vowel onset and C_2 at the vowel offset. In this section, the effects of primary and secondary place of articulation on F2 are considered more closely.

Consider first the mean and standard deviations associated with primary place of articulation. These are illustrated in Figure 3.14. The primary articulation of C_1 was found to be highly significant at the vowel onset (C1P: $F_{1,1158}$=30.93, p<0.0115). This was also true of C_2 at the vowel offset (C2P: $F_{1,1158}$=307.52, p<0.0087; C2S: $F_{1,1158}$=28.39, p<0.0129).

FIGURE 3.14. MEANS AND STANDARD DEVIATIONS FOR F2 AT THE VOWEL ONSET & OFFSET ASSOCIATED WITH PRIMARY ARTICULATION (POOLED DATA)

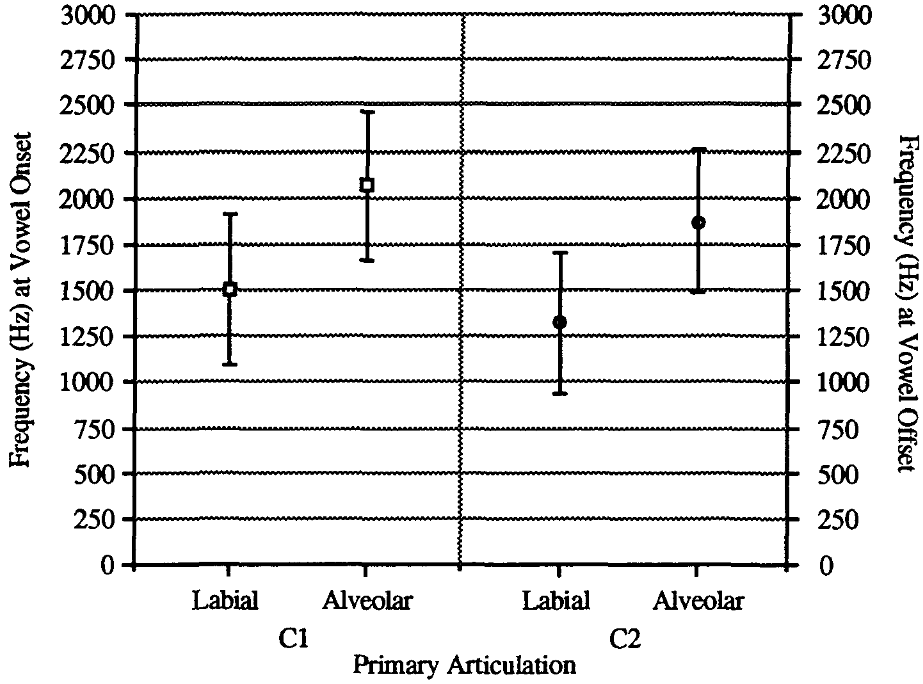


FIGURE 3.15. MEANS AND STANDARD DEVIATIONS FOR F2 AT THE VOWEL ONSET AND OFFSET ASSOCIATED WITH SECONDARY ARTICULATION (POOLED DATA)

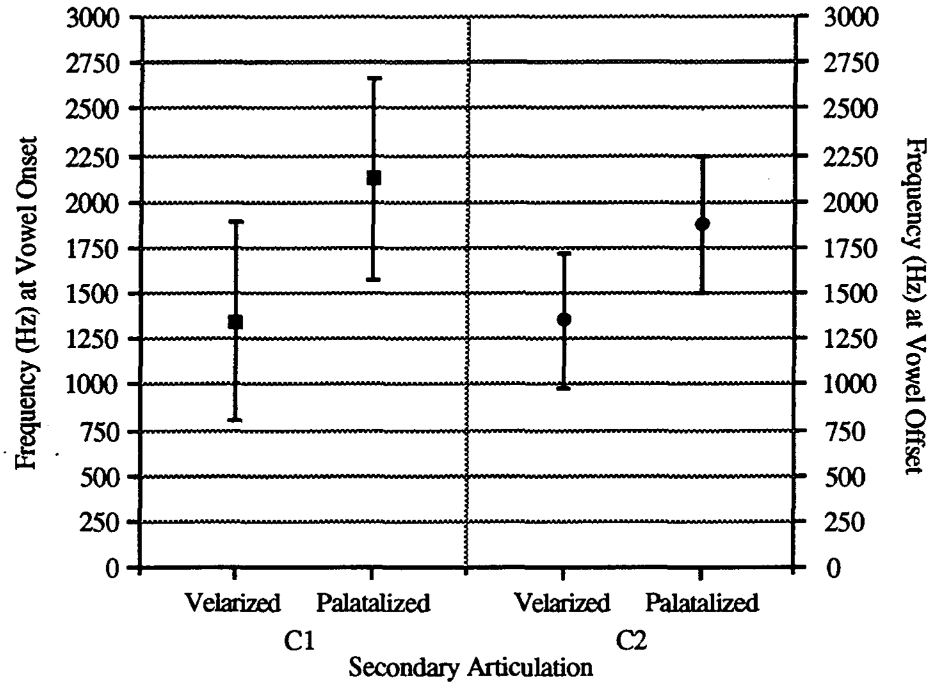
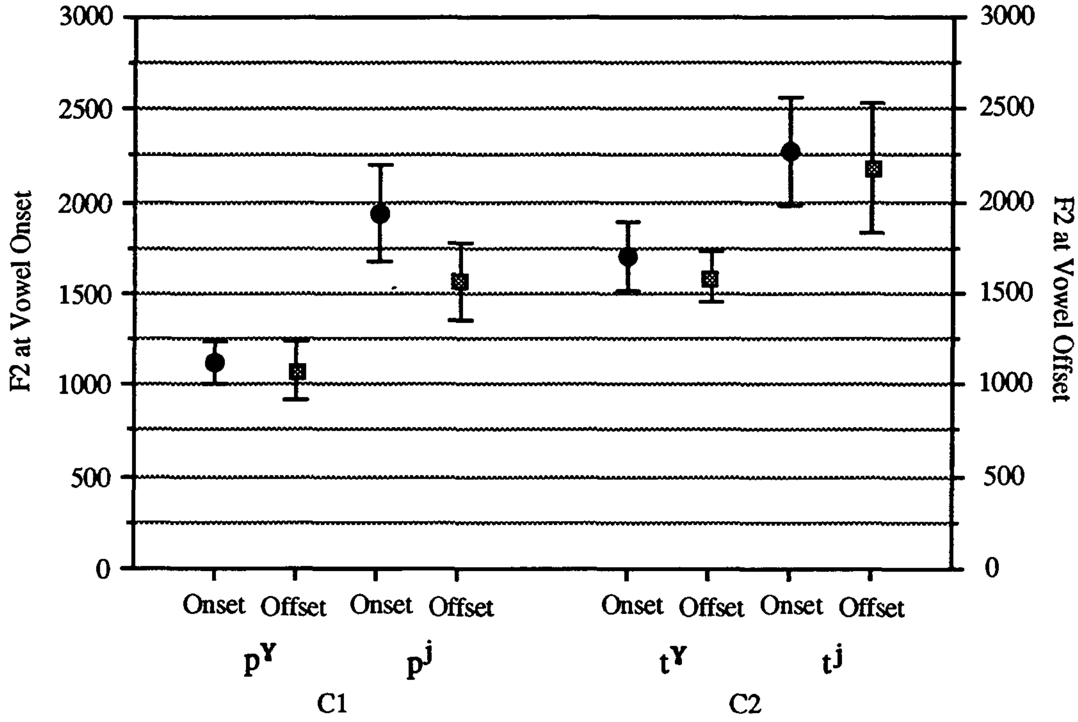


FIGURE 3.16. MEANS AND STANDARD DEVIATIONS FOR F2 AT THE VOWEL ONSET AND OFFSET ASSOCIATED WITH C1 AND C2 (POOLED DATA)



Interestingly, the mean values associated with the primary places of articulation differ depending on whether the consonant is initial or final. This difference is on the order of magnitude of 197 Hz for the bilabials and 179 Hz for the alveolars.

The variation associated with secondary articulation is illustrated in Figure 3.15. Again, these differences were found to be highly significant at the vowel onset as a function of C_1 (C1S: $F_{1,1158}=55.65$, $p<0.0050$) and at the vowel offset as a function of C_2 (C2S: $F_{1,1158}=28.39$, $p<0.0129$). There is also evidence of asymmetry depending on syllable position, but only in the palatalized consonants. The mean F2 is 247 Hz lower in syllable final position than in syllable initial. This asymmetry is not present in the case of the velarized consonants.

The means and standard deviations associated with the interaction [C1P x C1S] at the vowel onset and [C2P x C2S] at the vowel offset are plotted in Figure 3.16. The interaction [C1P x C1S] at the vowel onset was found to be significant ([C1P x C1S]: $F_{1,1160}=15.15$, $p<0.0301$); [C2P x C2S] at the vowel offset was not. Again, differences are observed as a function of syllable position; mean values are higher in initial position than they are in final position. These differences are on the order of magnitude of 50 to 100 Hz, with the exception of /pʲ/ which exhibits a much higher magnitude difference of 368 Hz.

There are several studies which have reported similar asymmetries in the articulatory domain (Houde 1968; Kent & Moll 1972b; Munhall et al. 1991). The question then arises as to whether or not the acoustic asymmetries here reflect the type of articulatory asymmetries observed in these studies. This is addressed in more detail in Chapter 6.

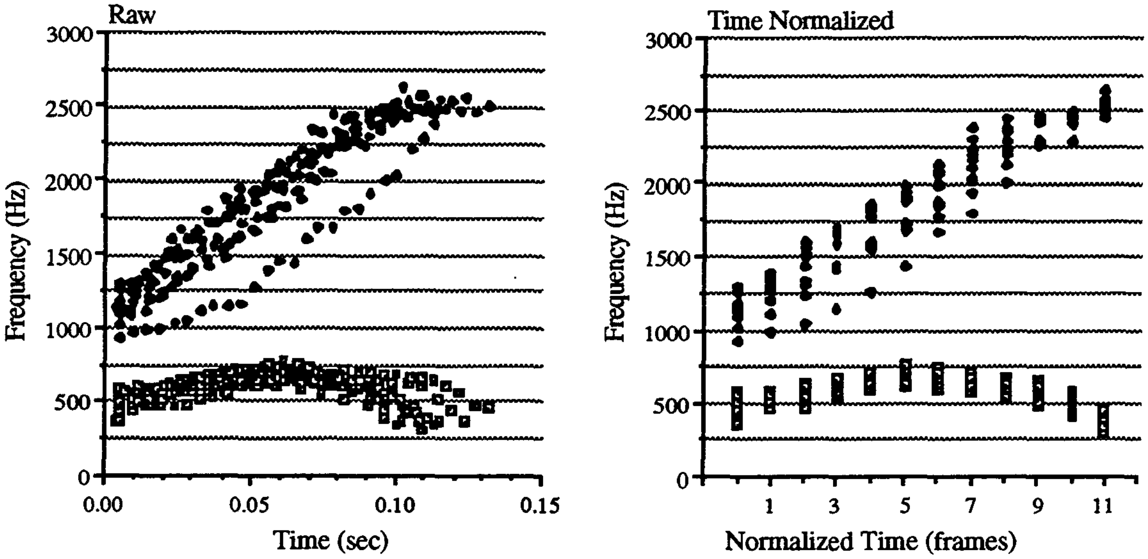
3.5. *STATISTICAL DESIGN II*

Examination of categorical effects at the vowel onset, offset and midpoint provides strong evidence that the Marshallese vowels can be modeled with no front/back target in the underspecification paradigm. Robust consonant-to-consonant articulation was found, as well as the strong consonantal effects on F2 at the vowel midpoint. There was some effect of vowel category at the vowel midpoint and onset; the magnitude of these effects was minor, and it was attributed to variation in constriction size and not to the presence of F2 targets associated with a front/back specification. If, as predicted, the Marshallese vowels can be modeled without reference to a vocalic F2 target, then a model based on C_1 and C_2 targets alone should accurately predict F2 in the vowel. Moreover, the accuracy of such a model should not significantly differ from a model which includes a vowel target.

To test these claims, the data were submitted to multiple linear regression analysis. Assuming that the F2 value at T_{onset} reflects the C_1 F2 target, and that the F2 value at T_{offset}

reflects the C_2 F2 target, then we can assess by means of regression analysis how accurately F2 at any intermediate time T_n can be predicted based on the C_1 and C_2 targets alone. Differences in the accuracy of a model based solely on $[C_1 \times C_2]$ with a model based on $[C_1 \times \text{VOW} \times C_2]$ can also be assessed. Borrowing a technique used by Browman & Goldstein (1991), two regression analyses are run, one with an intercept and one without an intercept, where the intercept term is associated with a vowel contribution. This comparison is based on the logic that if $F2=C_1\alpha_1+C_2\alpha_2+\beta$ and the intercept $\beta=0$, then $\alpha_1+\alpha_2$ is forced to equal 1. However, if $\beta\neq0$, then the accuracy of the model may be improved by inclusion of a constant term β associated with the vowel; i.e., if there is no F2 target in T_{mid} for the vowel, then in the absence of external factors (x=0), there will be no value for the dependent variable (y=0).

FIGURE 3.17. COMPARISON OF RAW AND TIME-NORMALIZED DATA FOR 10 REPETITIONS OF /pˠɐtʲ/ (DY)



It should be noted at this point that the model described above is based on "targets" which have already been adjusted for contextual variation. Given that the data showed considerable consonant-to-consonant coarticulation, the assumption that the formant frequency values at the vowel onset and offset correspond to the C_1 and C_2 targets, respectively, must be taken in this context; i.e., contextual variability associated with consonant-to-consonant coarticulation was not taken into account in the linear model - there was no attempt to normalize the initial and final F2 values to reflect "invariant" consonantal loci.

For purposes of the regression analysis, the F1 and F2 measures were time normalized so that statistical comparisons could be made across all C_1VC_2 sets. As Broad & Fertig (1970) point out, it is certainly arguable that the description of formant trajectories should be in terms of an absolute, rather than a normalized, time base. This follows from the premise that the dynamic and neuromuscular constraints on the articulatory mechanism are best described in terms of a relatively fixed set of time constants. This argument is well taken. However, as with Broad & Fertig (1970), time normalization is performed to accommodate the statistical analysis.

Time normalization involved calculating 12 equidistant time steps from the vowel onset to the vowel offset, based on percentage values of the vowel's overall duration. An interpolation algorithm was then applied to calculate the time normalized F1 and F2 values, based on the two nearest real-time measures. A comparison of the raw and normalized data for 10 repetitions of the utterance /pˠɐtʲ/ 'lower abdomen' for one speaker is presented in Figure 3.17. The raw data, represented in the left frame, is plotted as a function of real-time; the normalized data is plotted in the right frame as a function of normalized time steps. By time normalizing the data, multiple linear regression tests can be used to assess the relationship between the initial and final F2 values with each of the 10 intermediate values across all C_1VC_2 sets.

Multiple regression analysis can also be used to assess the relative importance of C_1 and C_2 in the time course of the F2 trajectory. This is done by calculating the standardized z-score form of the regression equation for each time point T_n. The variables are standardized by subtracting their means and dividing by their standard deviations. Since each variable in the standardized form of the regression equation has exactly the same standard deviation (1) and mean (0), the absolute values of the z-score coefficients (otherwise known as beta-coefficients) provide a comparison of C_1 and C_2 with respect to the magnitude of their effects at each time point.

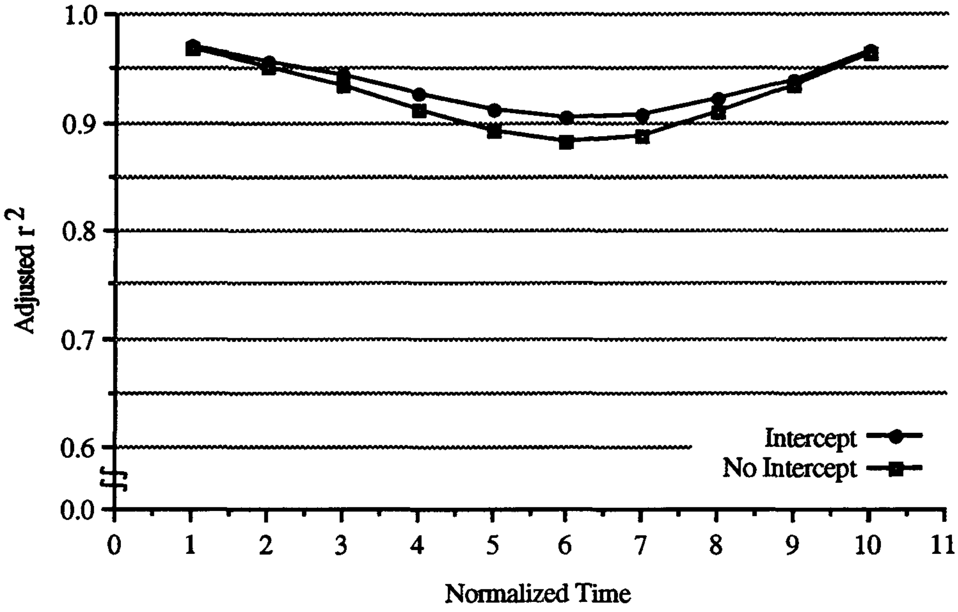
3.6. RESULTS

3.6.1. A $[C_1+C_2]$ MODEL VERSUS A $[C_1+VOWEL+C_2]$ MODEL

To test the hypothesis that a model based on C_1 and C_2 alone should predict F2 at any time point in the vowel with a high degree of accuracy, a regression model was constructed with a restriction that intercept=0. The accuracy of this 'no-intercept' model is illustrated in Figure 3.18 where the adjusted r^2 of the models is plotted as a function of normalized time. As shown, a model based on C_1 and C_2 alone predicts F2 throughout the vowel with a high degree of accuracy. Not surprisingly, the model is more accurate at the peripheries, but does not fall below 89% even at the vowel midpoint.

While it has been shown that a [$C_1 + C_2$] model predicts F2 with a high degree of accuracy, it remains to be seen how this model compares to one which includes a vowel contribution. To make this comparison, a regression model was constructed without a restriction on the intercept. The accuracy of this model is illustrated in Figure 3.18 where the adjusted r^2 of the intercept model (one which includes a vowel contribution) is plotted along with the no-intercept model (one based solely on C_1 and C_2). Care was taken to use the corrected total sums of squares in both models, so that a comparison of r^2 values would be valid. As evident in this plot, both models predict F2 throughout the vowel with a high degree of accuracy which falls off at the midpoint. Crucially, however, the intercept model does not significantly improve the accuracy of prediction; the greatest difference between the models is 0.02 at T_6.

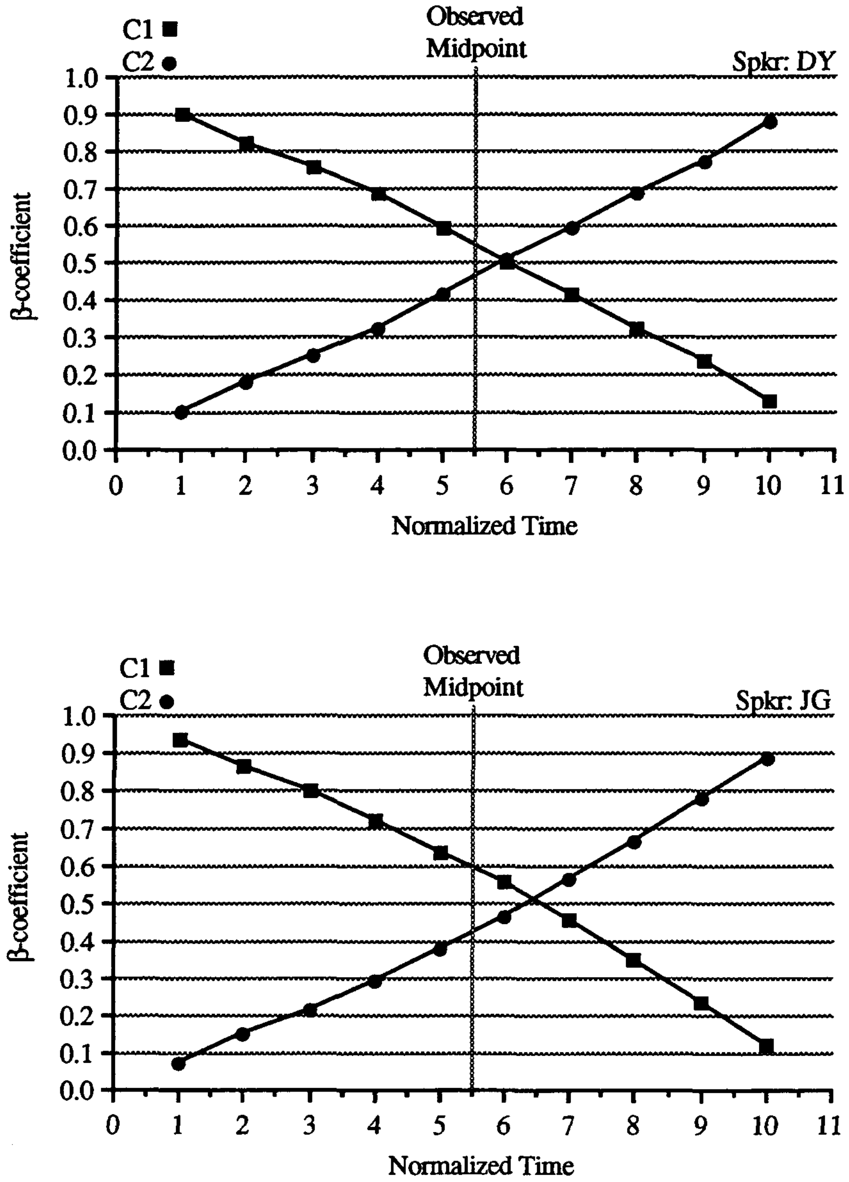
FIGURE 3.18. COMPARISON OF THE INTERCEPT VS. NO-INTERCEPT MODELS (POOLED)

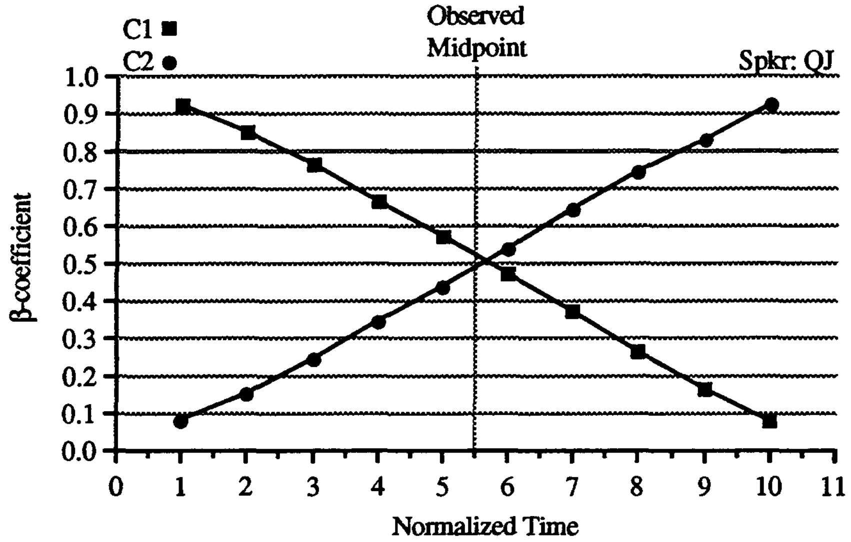


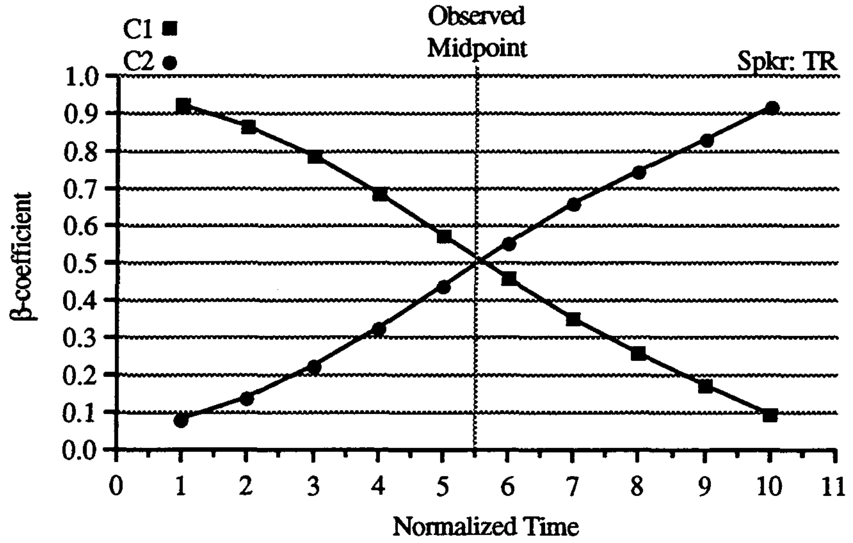
3.6.2. *ASYMMETRY IN CONSONANTAL EFFECTS*

The degree of asymmetry in the effects of C_1 and C_2 was also explored further by means of regression analysis. To assess the relative importance of the initial and final secondary articulations at a given time point, the regression equation was simplified to a standardized z-score form. The standardized equation expresses the correlation between two variables under the condition that all other concomitantly measured variables are held constant. Consequently, the beta-coefficients in the standardized equation provide a measure of the relative importance of C_1 versus C_2 at each time point.

FIGURE 3.19. RELATIVE INFLUENCE OF C_1 VS. C_2 (INDIVIDUAL DATA)

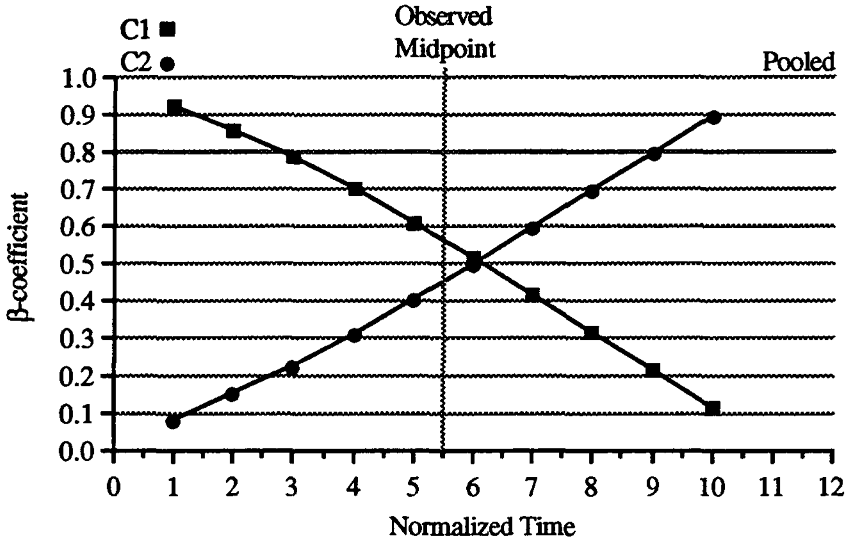






The beta-coefficients are plotted as a function of normalized time for each speaker in Figure 3.19; the same plot for the pooled data is in Figure 3.20. When the value is close to 1.0 for a given variable, that variable contributes more to determining the F2 value at that particular time than when it is close to 0. As shown, the influence of C1S persists beyond the vowel midpoint by approximately one normalized time step, reflecting the relative strength of carryover articulation as compared to anticipatory coarticulation that was seen earlier in the pooled data.

FIGURE 3.20. RELATIVE INFLUENCE OF C_1 VS. C_2 (POOLED DATA)



3.7. VARIATION IN F2 AS A FUNCTION OF INTERCONSONANTAL INTERVAL

Although the results presented thus far strongly support the underspecification hypothesis, there is still one relationship that needs to be examined before we can confidently conclude that the vowels in Marshallese /CVC/ syllables are underspecified. This is the relationship between F2 and duration. The presence of variation in F2 at T_{mid} as a function of vowel duration is important in that it would provide evidence for an alternative account for the Marshallese data which would attribute the absence of an observable F2 target in the vowel to the overlap of consonantal gestures. In this scenario, the vowel is fully specified for frontness/backness in the input to the phonetic component (possibly as central), but the mid-value F2 target projected from this feature is obscured due to the magnitude and phasing of the consonantal gestures. Here, the smooth transitions that serve as diagnostics for underspecification are attributed to articulatory overlap which effectively make extant targets invisible (Boyce, et al., 1991).

This alternative account is graphically illustrated in Figure 3.21 where the bold triangular areas represent hypothetical consonantal gestures associated with C_1 and C_2. These gestures are plotted in a space defined by magnitude and time, where magnitude is represented in terms of the total area of the gestures. As represented, if the consonantal gestures are of sufficiently great magnitude, then they could totally envelope the vowel gesture so that it is never physically observable, although it is in principle present.

Hypothetical targets and corresponding trajectories between them are overlaid for comparison.

FIGURE 3.21 GESTURAL OVERLAP

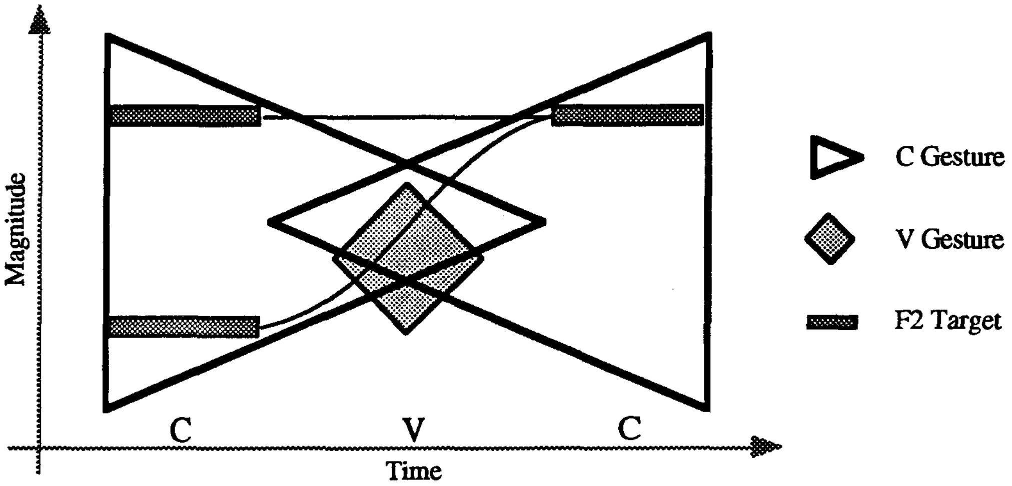
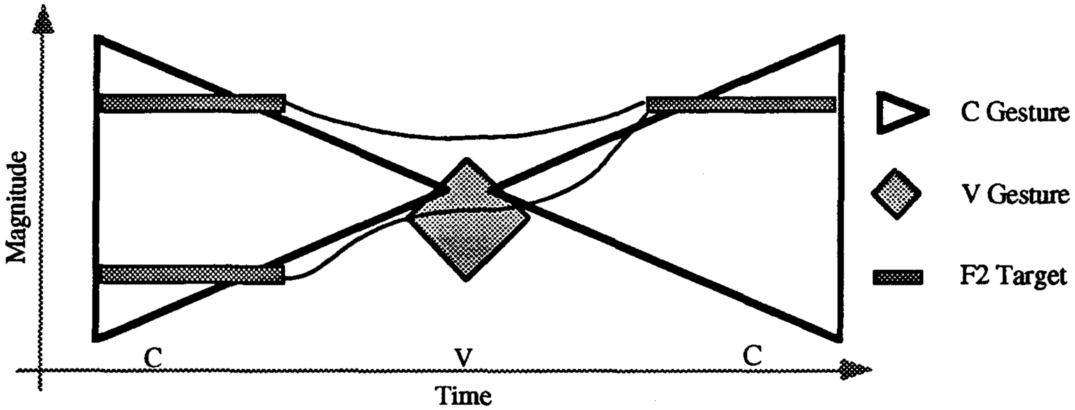


FIGURE 3.22. RESULTS OF AN INCREASE IN THE INTER-CONSONANTAL INTERVAL



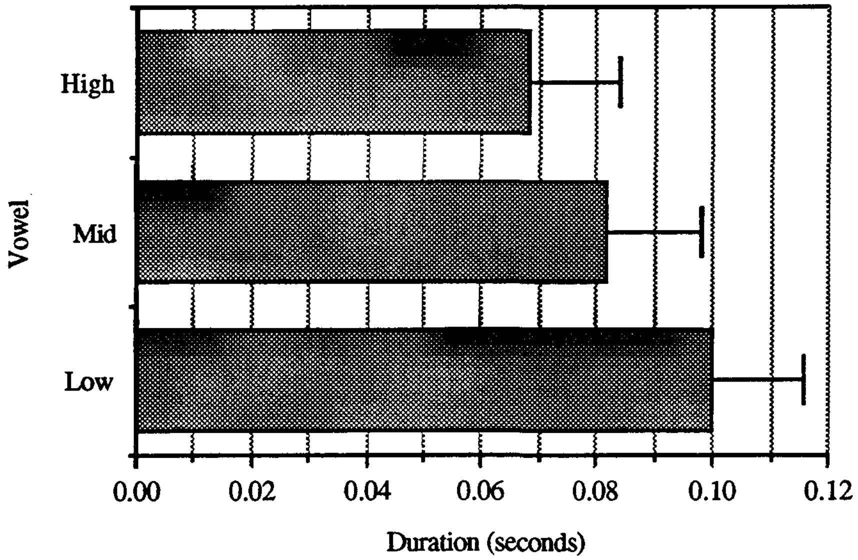
The hypothesis, as presented, is untestable. However, if we assume that vowel gestures are relatively constant or fixed in the time dimension (Fowler 1980; 1981), then this model predicts that as the inter-consonantal interval increases, the vowel target would surface. This is illustrated in Figure 3.22. Acoustically, this target should then influence the F2 trajectory between consonantal targets, providing a source of "gravitational-attraction" in the acoustic space, which would be observed as an inflection point or steady state.

3.7.1. MATERIALS

The prediction illustrated in Figure 3.22 was tested in a subset of the current data set consisting of the three vowel heights {/HIGH/, /MID/, /LOW/} in symmetric palatalized and velarized environments using correlation analysis. As vowel duration increased, the gestural overlap model considered above predicts that we should see different F2 values corresponding to the vocalic target. If so, then we should find a correlation between vowel duration and F2 at the vowel midpoint. We expect such a correlation to be most robust in the symmetrically palatalized context where F2 should decrease with increasing duration.

3.7.2. DURATION PROFILE

FIGURE 3.23. MEAN DURATIONS (POOLED DATA)



A profile of the durational characteristics associated with the vowel types is illustrated in Figure 3.23, where the mean durations for the /HIGH/, /MID/, /LOW/ are plotted. Further descriptive statistics for the duration parameter associated with the height contrasts are presented in Table 3.8. A one-factor analysis of variance shows the difference across the vowels to be highly significant for all speakers (DY: $F_{2,288}=85.70$, $p=0.0001$; JG: $F_{2,288}=111.51$, $p=0.0001$; QJ: $F_{2,288}=156.51$, $p=0.0001$; TR: $F_{2,288}=239.36$, $p=0.0001$). Repeated measures analysis of variance found the difference to be highly significant in the pooled data as well ($F_{2,1157}=449.15$, $p=0.0001$). This profile fits the general trends in intrinsic durational differences reported across languages (Lehiste 1970). Based on these results, we expect that any correlation between duration and F2 would show up in the /LOW/ vowel tokens, given that they showed the most variation in duration.

TABLE 3.8. DESCRIPTIVE STATISTICS FOR [DURATION x VOWEL] BY INDIVIDUAL SPEAKERS

SPKR	*VOWEL*	*MEAN*	*STD.DEV.*	*STD. ERROR*
DY	/low/	0.1057	0.0154	0.0015
	/mid/	0.0914	0.0152	0.0015
	/high/	0.0787	0.0107	0.0012
JG	/low/	0.1031	0.0161	0.0015
	/mid/	0.0828	0.0148	0.0015
	/high/	0.0716	0.0131	0.0015
QJ	/low/	0.0978	0.0145	0.0014
	/mid/	0.0798	0.0117	0.0012
	/high/	0.0639	0.0131	0.0015
TR	/low/	0.0937	0.0125	0.0012
	/mid/	0.0738	0.0104	0.0010
	/high/	0.0591	0.0091	0.0010
Pooled	/low/	0.1001	0.0154	0.0007
	/mid/	0.0819	0.0146	0.0007
	/high/	0.0683	0.0138	0.0008

3.7.3. CORRELATION

Correlation analysis was run on a subset of the data sorted by the three vowel categories in symmetric [PALATALIZED]x[PALATALIZED] and [VELARIZED]x[VELARIZED] contexts. The purpose of this test was to determine if there was a correlation between vowel duration and F2 at the vowel midpoint. If we assume a central target for the vowels, then we should see a positive correlation in the velarized contexts; i.e. as duration increases, then so should F2 at T_{mid}. Conversely, we should see a negative correlation in the palatalized contexts; i.e. as duration increases, F2 at T_{mid} should decrease.

The results of the correlation analysis, summarized in Table 3.9, showed no reliable variation in F2 at T_{mid} as a function of duration either for the individual speakers or the pooled data. There is one small corner of the data, the high vowels in the [PALATALIZED]x[PALATALIZED] context, where there is some trend toward a correlation in the pooled group. However, the direction of this correlation is not in the direction predicted by the overlap account. These results show that an increase in the interconsonantal interval does not reveal a vocalic target and that the prediction made by a gestural overlap account is not instantiated in the data. The argument against the overlap account is strengthened when we consider that the vowels were both stressed and in sentence final position, contexts in which we would expect the vowels to be as long as possible. This lends further support to the hypothesis that Marshallese vowel allophony can be accounted for in terms of vocalic underspecification and target-interpolation.

TABLE 3.9. SUMMARY OF THE CORRELATION ANALYSIS RESULTS

SPKR	*C1S*	*VOW*	*C2S*	*n*	*CORRELATION*	r^2
DY	VEL	HIGH	VEL	10	0.17	0.03
	VEL	MID	VEL	30	-0.35	0.12
	VEL	LOW	VEL	30	-0.04	0.00
	PAL	HIGH	PAL	20	0.10	0.01
	PAL	MID	PAL	20	-0.43	0.19
	PAL	LOW	PAL	40	-0.07	0.00
JG	VEL	HIGH	VEL	10	0.44	0.20
	VEL	MID	VEL	30	0.24	0.06
	VEL	LOW	VEL	30	-0.30	0.09
	PAL	HIGH	PAL	20	-0.10	0.01
	PAL	MID	PAL	20	0.10	0.01
	PAL	LOW	PAL	40	0.19	0.04
QJ	VEL	HIGH	VEL	10	0.24	0.06
	VEL	MID	VEL	30	-0.10	0.01
	VEL	LOW	VEL	30	-0.04	0.00
	PAL	HIGH	PAL	20	0.46	0.22
	PAL	MID	PAL	20	0.48	0.23
	PAL	LOW	PAL	40	-0.06	0.00
TR	VEL	HIGH	VEL	10	0.58	0.34
	VEL	MID	VEL	30	-0.49	0.24
	VEL	LOW	VEL	30	-0.25	0.06
	PAL	HIGH	PAL	20	0.11	0.01
	PAL	MID	PAL	20	0.43	0.18
	PAL	LOW	PAL	40	0.16	0.02
Pooled	VEL	HIGH	VEL	40	0.41	0.17
	VEL	MID	VEL	120	-0.03	0.00
	VEL	LOW	VEL	120	-0.12	0.01
	PAL	HIGH	PAL	80	0.65	0.42
	PAL	MID	PAL	80	0.41	0.17
	PAL	LOW	PAL	160	0.30	0.09

CHAPTER 4: THE LONG MEDIAL VOWELS

The arguments presented in Chapter 3 for the underspecification hypothesis are based on predictions of what would be expected in vowels that are not inherently defined along the front/back parameter. The short medial vowels have been presented as examples of such underspecified vowels. In this section, the spectral characteristics of phonologically long syllabic nuclei are presented as examples of vowels with phonetic F2 targets.

As discussed in Chapter 2, Bender analyzes the long vowels of Marshallese as underlying vowel-glide-vowel sequences. The medial glide is interpreted phonetically as a F2 target; i.e., the medial glide should project a F2 target associated with its phonological specification (/j/=[PALATAL]; /ɰ/=[VELAR]). Acoustically, this target should be observable as an inflection point, or possibly as a steady state, in the long vowel. To the extent that this holds true, the long vowels should exhibit spectral characteristics that contrast with the medial short vowels. These contrasts are laid out in section 4.2.

4.1. METHODOLOGY

The speech data for this portion of the study was collected from one speaker, DY. A small word list, presented in Table 4.1, was compiled to illustrate minimal contrasts between short and long phonetic vowels. The lexical items in the list with phonetically long vowels are of the underlying form /C_1VGVC_2/. The /C_1VC_2/ utterances were taken from the corpus used in Chapter 3.

TABLE 4.1. SHORT~LONG VOWEL COMPARISONS

CANONICAL		*EXAMPLES*	
SHORT	*LONG*	*SHORT*	*LONG*
$C_1^iVC_2^i$	$C_1^iVG_iVC_2^i$	/tˠɐpˠ/ 'foggy'	/tˠɐɰɐpˠ/ 'although'
$C_1^iVC_2^i$	$C_1^iVG_jVC_2^i$	/tʲɐtʲ/ 'snapper fish'	/tʲɐɰɐtʲ/ 'charge'
$C_1^iVC_2^j$	$C_1^iVG_iVC_2^j$	/tʲəpˠ/ 'type of pandanus'	/tʲəjəpˠ/ 'coconut juice container'
$C_1^iVC_2^j$	$C_1^iVG_jVC_2^j$	/tʲɐtˠ/ 'deep water'	/tʲɐɰɐtˠ/ 'shot of whiskey'

The speech was recorded on analog cassette tapes and acoustically analyzed following the procedures outlined in Chapter 3. Three repetitions were elicited for each long vowel token. The resulting F1, F2 and duration measures for the long vowels were pooled with the corresponding short vowel data and coded for LENGTH(SHORT; LONG). The data for each pair of words were then submitted to analysis of variance to test for variation in F2 at T_{mid} as a function of LENGTH.

4.2. PREDICTIONS

While the set of comparisons is small, the four canonical contrasts $C_1^iVC_2^i$ vs $C_1^iVG_iVC_2^i$, $C_1^iVC_2^i$ vs $C_1^iVG_jVC_2^i$, $C_1^iVC_2^j$ vs $C_1^iVG_iVC_2^j$ and $C_1^iVC_2^j$ vs $C_1^iVG_jVC_2^j$ are represented. The superscripts associated with the consonants stand for secondary articulations, where $i \neq j$. These four sets were chosen to illustrate specific predictions made by Bender's analysis of the long vowels that revolve around the assumption that the F2 characteristics of the medial long vowels are determined by the interaction between the secondary articulation specifications of C_1, G, and C_2.

$C_1^iVC_2^i$ vs $C_1^iVG_iVC_2^i$ and $C_1^iVC_2^i$ vs $C_1^iVG_jVC_2^i$ represent comparisons which involve symmetric initial and final secondary articulation contexts. The long vowel tokens differ with respective to their hypothetical medial F2 targets. In $C_1^iVG_iVC_2^i$, the medial target is the same as the peripheral targets; in $C_1^iVG_jVC_2^i$, the medial target is different from the peripheral targets. Thus, in the $C_1^iVC_2^i$ vs $C_1^iVG_iVC_2^i$ pair, the tests should show no significant difference in F2 at T_{mid}. This is illustrated in Figure 4.1; idealized F2 targets and trajectories are presented for the short vowel token in the left frame and for the long vowel token in the right frame.

FIGURE 4.1. PREDICTED VARIATION IN $C_1^iVC_2^i$ VS $C_1^iVG_iVC_2^i$

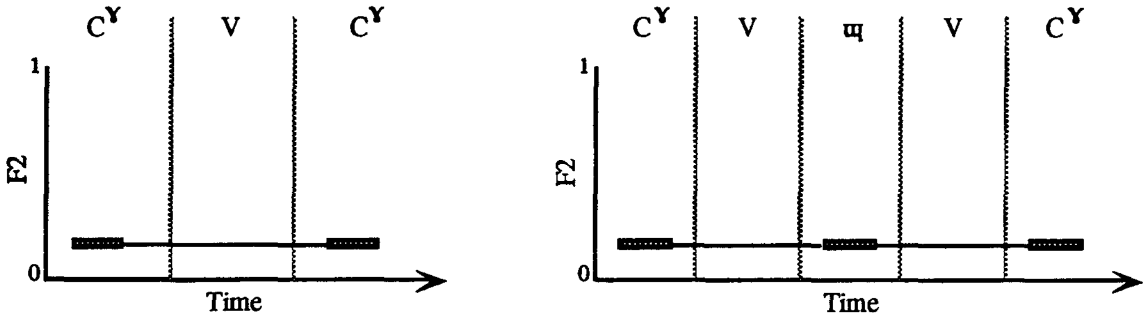
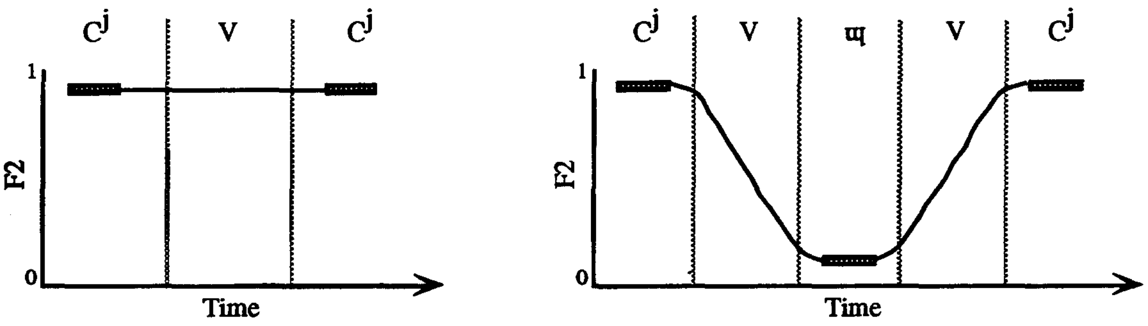
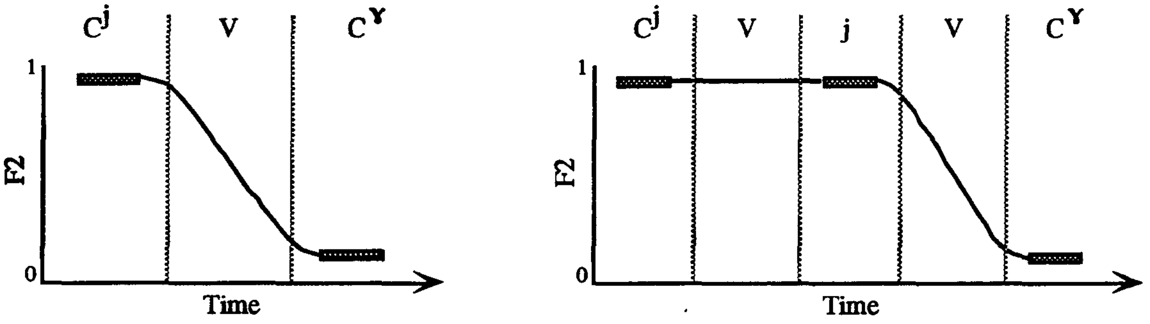


FIGURE 4.2. PREDICTED VARIATION IN $C_1^iVC_2^i$ VS $C_1^iVG_jVC_2^i$



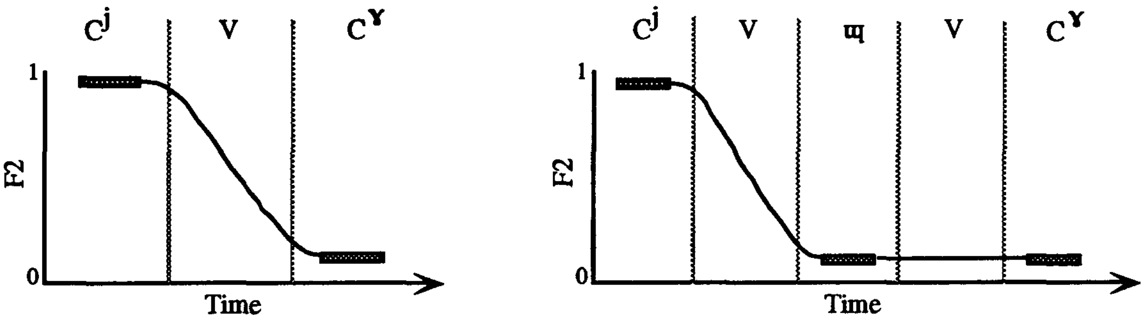
In the $C_1^iVC_2^i$ vs $C_1^iVG_jVC_2^i$ pair, the presence of a medial F2 target that differs from the peripheral F2 targets would result in a convex trajectory shape. In other words, the presence of this medial target should result in observable deviation in the F2 trajectory from the projected uninterrupted course seen in the underspecified /CVC/ tokens. This is illustrated in Figure 4.2.

FIGURE 4.3. PREDICTED VARIATION IN $C_1^iVC_2^j$ VS $C_1^iVG_iVC_2^j$



The two remaining pairs of contrasts represent examples in which the initial and final targets are different. The hypothetical medial target in the long vowel tokens will necessarily differ from one or the other peripheral target; i.e. it will be the same as the initial target and differ from the final, or it will be the same as the final target and differ from the initial. When it is the same as the initial target, as illustrated in the right frame of Figure 4.3, we would expect a level trajectory until the medial target is met, followed by a transition from the medial target to the final target. This should contrast with the F2 trajectory in the short vowel tokens, illustrated in the left frame of Figure 3.21. When the medial target is the same as the final target, the mirror image of the trajectory shape predicted in Figure 4.3 is expected. This is illustrated in Figure 4.4.

FIGURE 4.4. PREDICTED VARIATION IN $C_1^iVC_2^j$ VS $C_1^iVG_jVC_2^j$

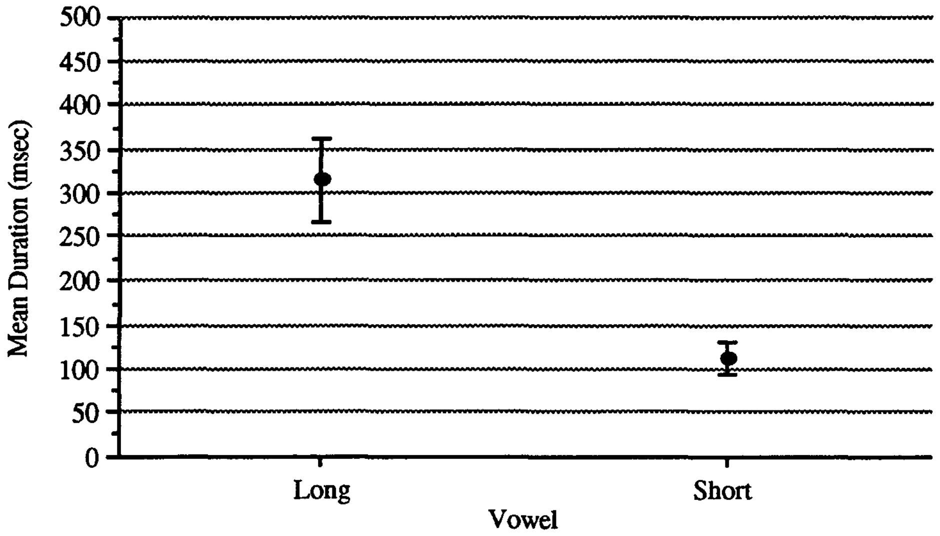


In summary, the theory predicts that a medial target that is not the same as both the initial and final targets will result in a diphthongal F2 trajectory that differs from that observed in the short vowels where there is no medial target posited.

4.3. *RESULTS*

4.3.1. *DURATION*

FIGURE 4.5. MEAN DURATION AS A FUNCTION OF VOWEL LENGTH



Durationally, the short and long vowels were found to exhibit statistically significant variation in length ($F_{1,49}$=517.59; p=0.0001). A histogram illustrating this difference is presented in Figure 4.5. The long vowels are longer than the short vowels on average by a factor of three.

4.3.2. VARIATION IN F2

Examination of spectrograms shows variation in the F2 trajectory shapes across vowel length categories as predicted by the medial target account of the long vowels. Sample F2 trajectories from tokens of /tˠɐpˠ/ and /tˠɐɰɐpˠ/, illustrating the $C_1^iVC_2^i$ vs $C_1^iVG_iVC_2^i$ contrast, are presented in Figure 4.6. The short vowel token is presented in the left frame and the long vowel token in the right frame. The time axis differs for each frame.

The F2 trajectories in these two tokens are similar. Both exhibit a relatively linear trajectory shape (allowing for the labial transition into the final consonant) with a slight negative slope reflecting the asymmetry in initial and final targets discussed in section 3.6. And while the shape of the F2 track in the long vowel token deviates a bit more from a linear trajectory than the short vowel F2 track, statistical comparisons of F2 at T_{mid} showed no significant variation across the two length categories as the theory predicts. This is illustrated in Figure 4.7.

In the remaining comparisons, the theory does predict a difference. Consider next the pair /tʲɐtʲ/ and /tʲɐɰɐtʲ/, representing a symmetric palatalized context with a hypothetical medial velar target in the long vowel token. Sample spectrograms are presented in Figure 4.8. Again, the short vowel is presented in the left frame and the long vowel in the right frame. The F2 trajectories obviously differ in this pair. In the long vowel token, there is a clear inflection point associated with the medial target that forces the F2 downward from the initial palatal F2 target. F2 then rises away from the medial velar F2 target to the final palatal F2 target. This contrasts with the time course of the F2 trajectory in the targetless short vowel which exhibits no inflection point. The differences in the F2 trajectories are as predicted. Statistical comparisons of F2 at T_{mid} showed significant variation across the two length categories. The mean F2 values for the short and long vowel tokens are plotted in Figure 4.9.

The F2 trajectory comparisons in asymmetric secondary articulation contexts also exhibit contrasts as predicted by the model. Consider first the difference between /tʲəpˠ/ and /tʲəjəpˠ/ in Figure 4.10. The hypothetical medial target in /tʲəjəpˠ/ differs from the final target but is the same as the initial. Accordingly, we see a steady state resulting from the movement from the initial to medial target, followed by a falling trajectory as the transition from the medial to final target takes place. The statistical comparison of F2 at T_{mid} showed significant variation across the two length categories, affirming that the F2 trajectory traverses different paths, at least at the vowel midpoint. The mean F2 values for the short and long vowel tokens are plotted in Figure 4.11.

FIGURE 4.6. SAMPLE F2 TRAJECTORIES FOR /t^{Y}ɐp^{Y}/ VERSUS /t^{Y}ɐɰɐp^{Y}/

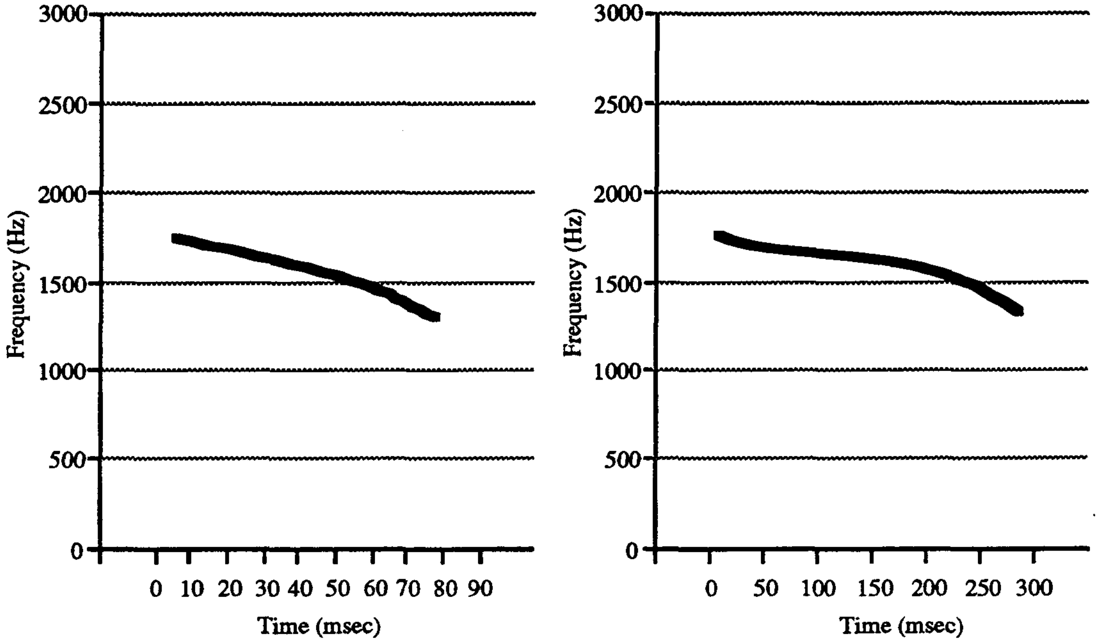


FIGURE 4.7. MEAN F2 AT T_{MID} FOR /t^{Y}ɐp^{Y}/ VERSUS /t^{Y}ɐɰɐp^{Y}/

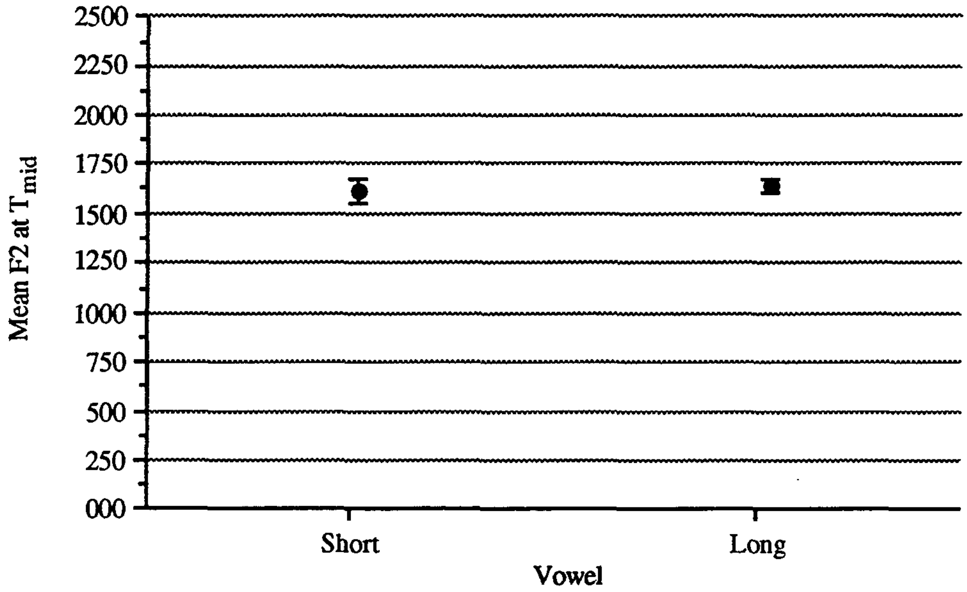


FIGURE 4.8. SAMPLE F2 TRAJECTORIES /tʲɐtʲ/ VERSUS /tʲɐɰɐtʲ/

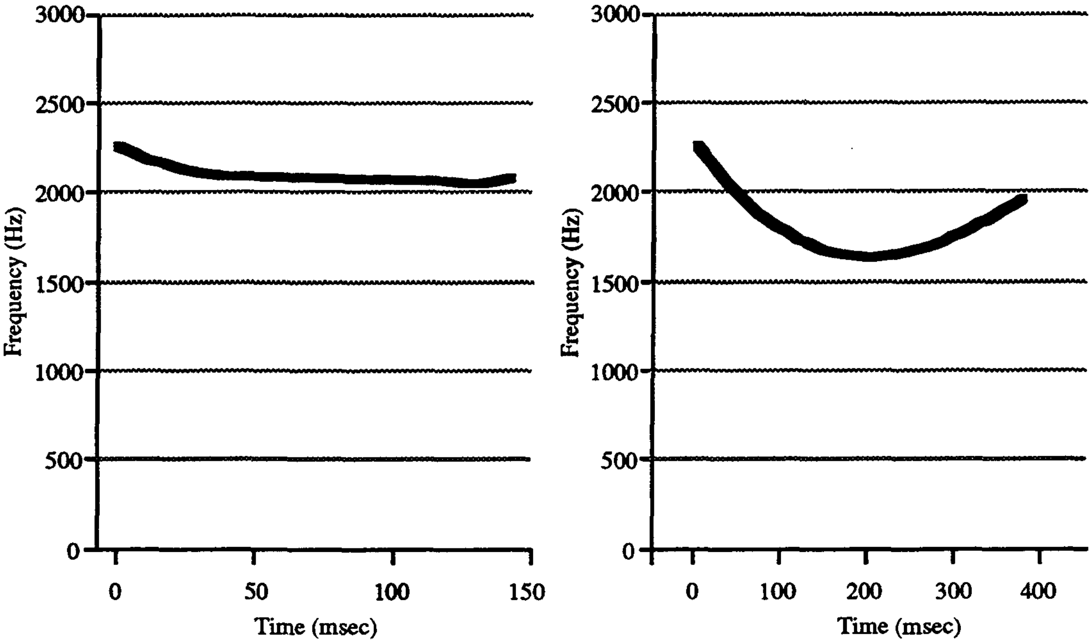


FIGURE 4.9. MEAN F2 AT T_{MID} FOR /tʲɐtʲ/ VERSUS /tʲɐɰɐtʲ/

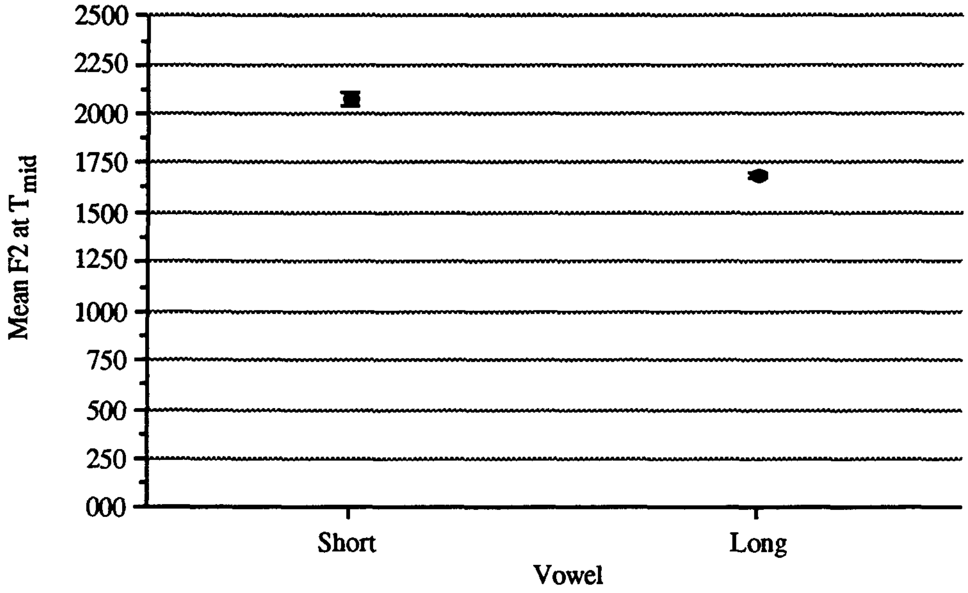


FIGURE 4.10. SAMPLE F2 TRAJECTORIES FOR /tʲəpˠ/ VERSUS /tʲəjəpˠ/

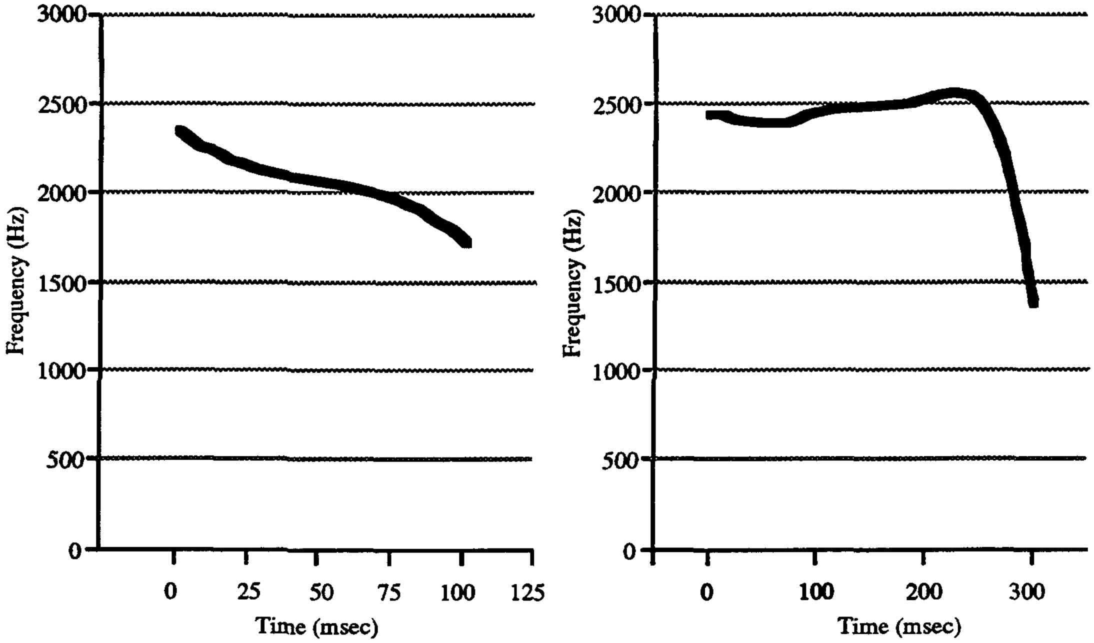


FIGURE 4.11. MEAN F2 AT T_{MID} FOR /tʲəpˠ/ VERSUS /tʲəjəpˠ/

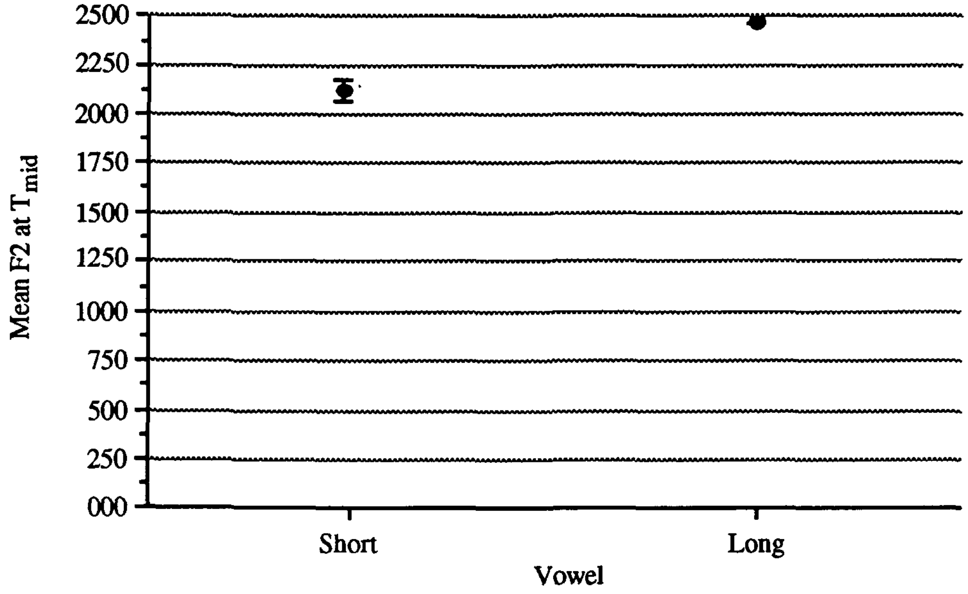


FIGURE 4.12. SAMPLE F2 TRAJECTORIES FOR /tʲɐtˠ/ VERSUS /tʲɐɰɐtˠ/

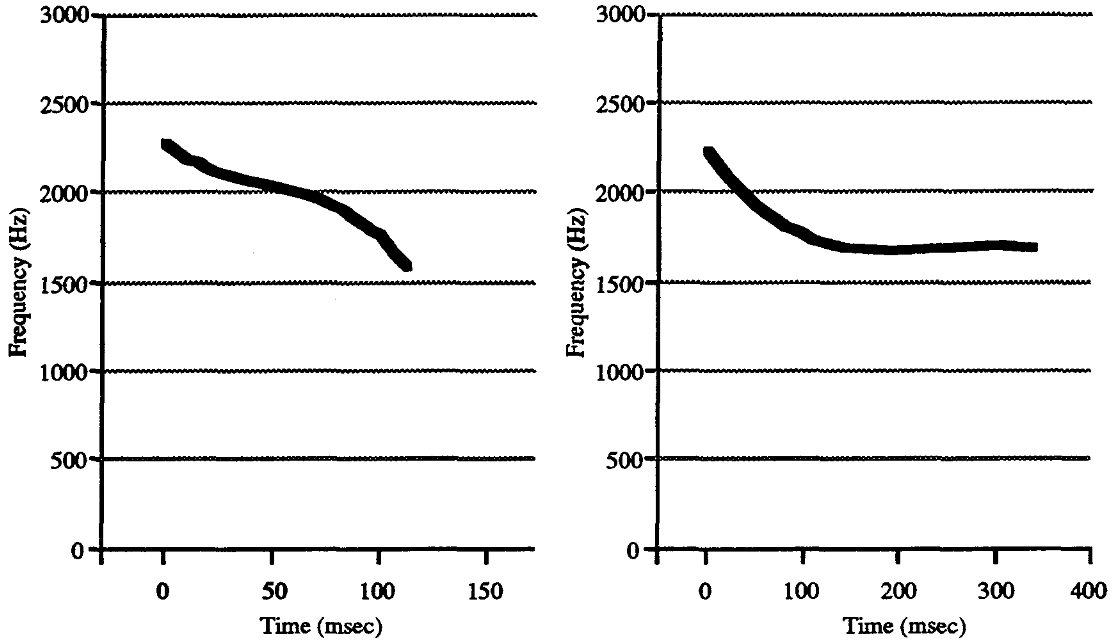
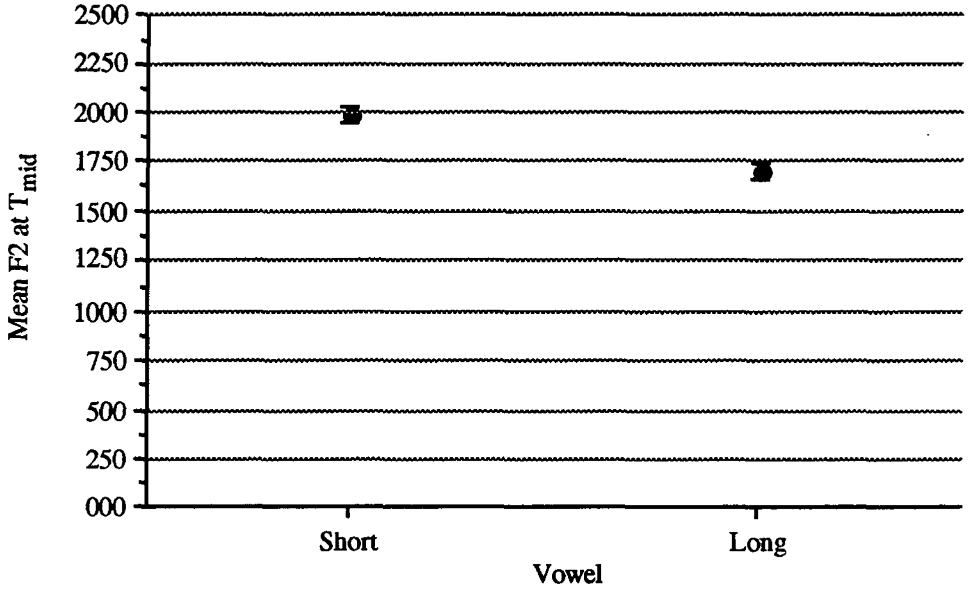


FIGURE 4.13. MEAN F2 AT T_{MID} FOR /tʲɐtˠ/ VERSUS /tʲɐɰɐtˠ/



The last pair examined, /tʲɐtˠ/ versus /tʲɐɰɐtˠ/, also showed distinct F2 trajectory shapes. In /tʲɐɰɐtˠ/, the hypothetical medial target differs from the initial target, and as expected, we find a falling transition from the initial palatal F2 target to the medial velar F2 target. This is illustrated in the right frame of Figure 4.12. This falling transition is then followed by a steady state which persists into the final consonant as predicted. The F2 trajectory in the long vowel token clearly differs from the trajectory in the short vowel token. Statistical comparison of F2 at T_{mid} showed significant variation across the two length categories. The mean F2 values for the short and long vowel tokens are plotted in Figure 4.13.

Before turning to the discussion, it should be noted that while the F2 trajectory for /tʲəjəpˠ/ in Figure 4.10 supports the medial target hypothesis, there is an aspect of the F2 contour that is slightly different from that predicted. Instead of a gradual transition from the medial target to the final target in the long vowel token, we find an rapid transition taking place over a relatively short time window. This contrasts with the relatively slow transitions observed for /tʲɐɰɐtʲ/ in Figure 4.8 and /tʲɐɰɐtˠ/ in Figure 4.12.

4.4. DISCUSSION

In Chapter 2, it was predicted that Bender's phonological account of the long vowels (/CVGVC/ -> [CVːC]) leads us to expect diphthongs with F2 transition patterns that contrast with those in the phonological short vowels (/CVC/ -> [CVC]). The acoustic data that have been presented in this chapter confirms these predictions. Moreover, the long vowel tokens that were examined all exhibited F2 trajectories which support the medial target hypothesis. Accordingly, the medial long vowels can be said to represent examples of syllables with phonetic targets in the nucleus. As such, they offer a clear contrast to the /CVC/ syllables where there are no targets posited in the nucleus.

The pairwise statistical comparisons, summarized in Table 4.2, verify what is visually evident. As predicted, there is no significant variation in F2 at T_{mid} in the /tˠɐpˠ/ vs /tˠɐɰɐpˠ/ comparison. However, for the remaining three pairs, the statistical tests showed highly significant effects. The magnitude of the variation, calculated as the difference between the mean F2 at T_{mid} for the short vowels and the mean F2 at T_{mid} for the long vowel, is extremely robust. Moreover, the direction of these effects follows the trends predicted by the medial target account of the long vowels.

TABLE 4.2. SUMMARY OF PAIRWISE COMPARISONS

CONTRAST	*F*	*p*	*MAGNITUDE (HZ)*
/tˠɐpˠ/ vs /tˠɐɰɐpˠ/	0.238	0.6350	-18.85
/tʲɐtʲ/ vs /tʲɐɰɐtʲ/	355.803	0.0001	382.33
/tʲəpˠ/ vs /tʲəjəpˠ/	126.518	0.0001	-349.07
/tʲɐtˠ/ vs /tʲɐɰɐtˠ/	114.887	0.0001	278.30

The medial target interpretation of Bender's phonological /CVGVC/ account of the long vowels, illustrated in Figures 4.1 through 4.4, is supported by the F2 trajectories examined. There was no evidence that the abstract glide is present phonetically. If there were a phonetic glide, i.e., a narrowing of the constriction, then a lowering of F2 might be expected medially in the syllabic nucleus. This was not borne out in the data, a fact which does not by itself preclude the glide's existence at a deeper level of representation. However, there are further problems rooted in purely phonological analysis of issues, such as reduplication, if the phonetic long vowels are analyzed as involving an abstract underlying glide (Byrd 1992). This suggests a more concrete analysis involving phonemic length differences as opposed to derived length differences. The issue is clouded further by at least one native speaker's intuition that lexical items of the form [CVːC] are disyllabic, an intuition which seems to support the abstract glide hypothesis. However, it could be the case that the native speaker is counting morae, not syllables. Regardless, this aspect of the Marshallese phonology remains a problem that warrants further research.

In terms of the phonetic framework adopted here, there is a problem with representing underlying long vowels with a front~back specification in their matrix. Presumably, the F2 target projected from this specification would occupy the entire time domain defined by the syllabic nucleus, resulting in long steady state accompanied by rapid transitions over relatively short time windows. This is illustrated in Figure 4.14 for the item /tʲɐɰɐtʲ/.†

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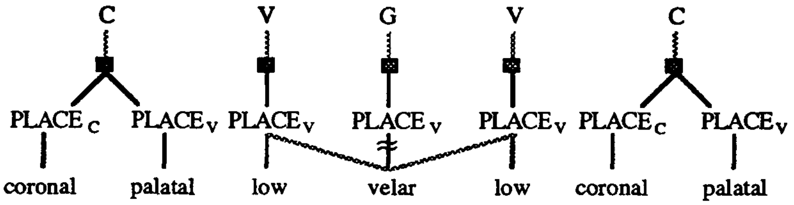
† Note that there is non-uniqueness problem here in so far as the steady state predicted by an analysis which posits underlying long vowels could also be derived in an analysis in which vowel length is derived. Consider, for example, a rule of bidirectional spreading:



The result of bidirectional spreading is to effectively extend the time domain of the glides feature by

However, the F2 trajectory that we observed exhibited an inflection point with gradual transitions, more in line with the predictions made by the medial target model, as illustrated in Figure 4.15.

FIGURE 4.14. F2 TRAJECTORY FOR /tʲɐɰɐtʲ/ PREDICTED BY AN UNDERLYING LONG VOWEL ANALYSIS

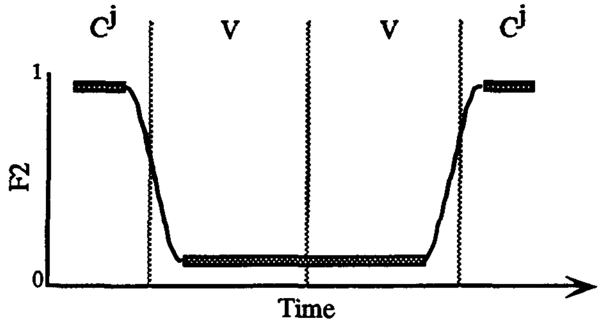
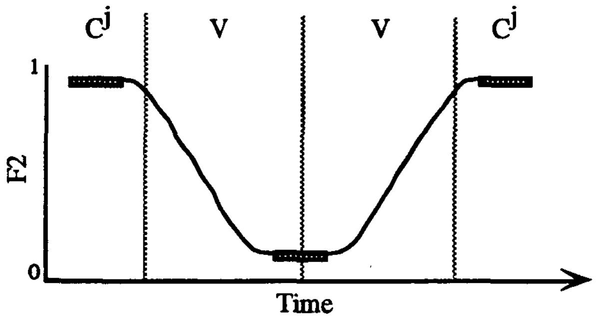


FIGURE 4.15. F2 TRAJECTORY FOR /tʲɐɰɐtʲ/ PREDICTED BY A MEDIAL TARGET ANALYSIS



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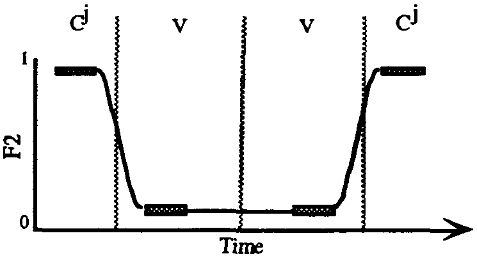
assigning the feature value to the vowels. Since targets are assumed to be projected from features, then the phonetic component would subsequently assign targets to these vowels. Assuming that targets share in the same linear precedence relations as segments, then the spreading account predicts that the surface long vowels should exhibit quick transitions into and out of the long vowel, with a steady-state F2 reflecting the tongue-body position defined by the medial velar target associated with both vocalic timing slots.



A rapid transition of the type predicted in Figure 4.15 was only found in one of the long vowel tokens, /tʲəjəpˠ/, and it is difficult to assess whether or not this rapid transition reflects a more general trend given the relatively small sample size and the restricted contexts in which the long vowels were examined. Given the absence of this rapid transition in most of the tokens examined, we speculate that this is not a general trend. At the same time, it is not clear why /tʲəjəpˠ/ alone should exhibit the rapid transitions. Analysis of more tokens in all the possible contexts would offer further insight into this question.

Regardless, the F2 trajectories exhibited by the long vowels are clearly different from those exhibited by the short vowels. These differences are argued to stem from the absence of a vocalic F2 target associated with an underlying front~back specification in the short vowels, versus the presence of a medial F2 target in the long vowels.

CHAPTER 5: THE F2 TRAJECTORY

It was initially assumed at the onset of this study that movement from acoustic target to acoustic target was essentially linear (Holmes, et al. 1964; Klatt 1976; Keating 1988; Wright and Elliott 1990). The efficacy of the linear regression model in Chapter 3 could be interpreted as further support for this assumption. However, visual examination of spectrograms shows that the F2 trajectories are often curvilinear, suggesting that the interpolation function is best characterized in other than strictly linear terms. In this chapter, the F2 trajectory is examined in more detail, and its shape is quantitatively characterized in terms of time-dependent functions. The purpose in estimating the F2 trajectory is to ascertain what type of function best describes the movement from the C_1 target to the C_2 target and to assess variation across the consonantal contexts under consideration. The resulting functions serve to provide a basis from which to discuss the F2 formant trajectories vis-a-vis the question of vocalic underspecification. No claims are being made that the functions somehow reflect the dynamic processes of speech production which give rise to the observed formant motions.

5.1. METHODOLOGY

A trajectory estimation technique, described below, was applied to the raw F2 measures from a subset of the /CVC/ corpus collected from the four speakers, consisting of /pˠVpˠ/ and /tʲVtˠ/ tokens, where /V/ ranged over the three phonemic vowel categories /HIGH/, /MID/ and /LOW/. The /pˠVpˠ/ set represents a symmetric secondary articulation context while the /tʲVtˠ/ set represents an example of an asymmetric secondary articulation context. Primary place of articulation could not be kept constant across the two sets due to gaps in the data and was therefore controlled only within each set.

5.1.1. TRAJECTORY ESTIMATION

Trajectory estimation was conducted within a least-squares based polynomial regression model, $y_i = \alpha_1 x_i + \alpha_2 x_i^2 + \ldots + \alpha_n x_i^n + b$, where y=F2 (Hz) and x=TIME (msec). The resulting model characterizes the trajectory as a time-dependent function and is amenable to the requirement that the interpolation function should generate the F2 trajectory from the initial consonantal target to the final consonantal target in CVC sequences with minimal error.

The choice of polynomial functions (including a first-order linear function) was initially determined by visual examination of the F2 trajectories and then verified by exploratory procedures comparing 3rd-order polynomial curve-fits with exponential curve-fits on 10 randomly chosen CVC tokens. A 3rd-order model was chosen on the basis of the assumption that the trajectories would exhibit at most two bends - one in the transition out of the initial consonant and another in the transition into the final consonant. Exponential functions were chosen for comparison because of their appearance in various models in the literature (Lindblom 1963; Rabiner 1969; Lawrence 1974; Fujisaki & Higuchi 1979; Broad & Clermont 1987; Imaizumi, et al. 1991).

5.1.2. POLYNOMIAL VERSUS EXPONENTIAL FITS

These comparisons consistently found that 3rd-order polynomial functions provided better fits than exponential functions. Sample comparisons are provided in Figures 4.1 through 4.6. The polynomial and exponential curve-fits are superimposed on the measured F2 values for each vowel in the left frames. The corresponding residual error is plotted as a function of time in the right frames.

The difference in the goodness-of-fit, based on the respective r^2 scores, was striking in the case of the trajectories in the symmetric environment, but only marginal for the trajectories in the asymmetric context. Comparisons of the residual error, however, show that the two types of fit compare more closely across the two contexts than suggested by the r^2 scores: the error profile and residual RMS values are relatively consistent across the two contexts.

The polynomial functions have the advantage of being able to capture the curvature present in the F2 trajectories. In both contexts, the fits based on the exponential functions are essentially linear, and fail to capture this curvature. This is corroborated by the curvilinear trend in the distribution of error over time for the curve-fits generated by the exponential functions.

Another way of conceptualizing the differences, suggested by Maddieson (personal communication) is to partition the source of variance to linear and nonlinear factors. We hypothesize that the linearity observed in the trajectories is attributable to the presence of peripheral targets associated with C_1 and C_2, which we assume is well approximated by linear interpolation. The nonlinearities are interpreted as stemming from articulator sluggishness and/or the inherent nonlinear mapping between articulatory~acoustic states. In the symmetric case, the latter seems to be the dominant component (based on preliminary assessments) in determining the variance of F2, and by definition, is not well-captured by a linear model. Moreover, the nonlinearities seem to be strongest at the vowel peripheries, especially at the vowel onset, as evident in the residual error profiles in Figures 5.1 through

5.3. The magnitude of the error is much greater in the first 10 to 20 milliseconds of the vowel than in the rest. The exponential functions do not provide good estimates because the best-fits are nearly linear. In the asymmetric case, linearity seems to play a more dominant role. This is discussed in more detail in section 5.3.

It is interesting to note that the trajectories in the symmetric contexts could be generated with two smoothed exponential functions, where the first defined the trajectory from the initial target to a target specified at the vowel midpoint, and the second defined the trajectory from that midpoint to the final target. However, this amounts to positing a vowel target, a hypothesis for which there is little evidence, as discussed in Chapter 3. Thus, the use of an exponential function to generate the trajectories in symmetric secondary articulation contexts is rejected. This, in addition to the desiderata that a single type of function should be applied in estimating the trajectories in both contexts, motivated the use of polynomial functions to model the interpolation function.

FIGURE 5.1. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE LOW VOWEL IN THE SYMMETRIC CONTEXT

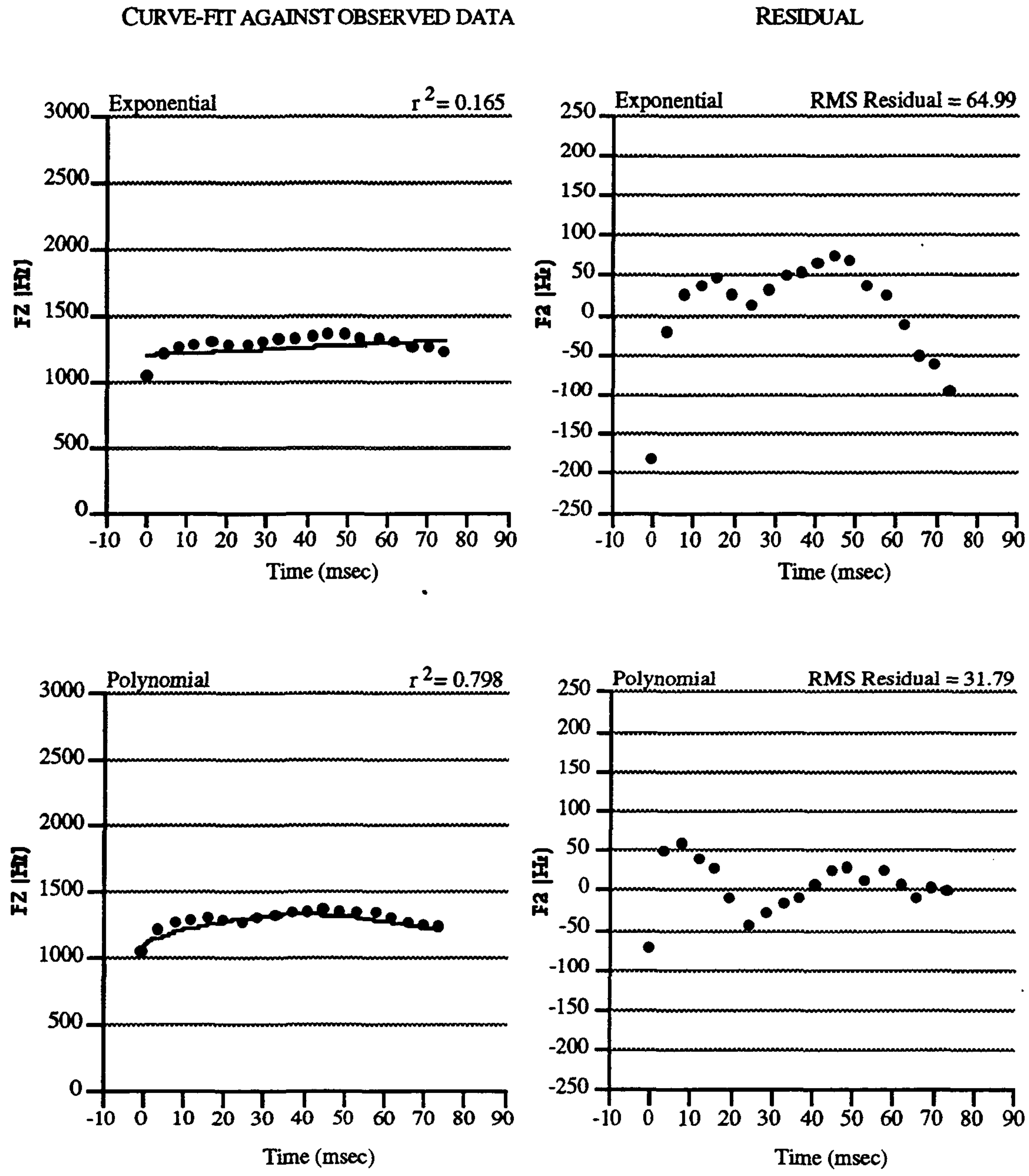


FIGURE 5.2. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE MID VOWEL IN THE SYMMETRIC CONTEXT

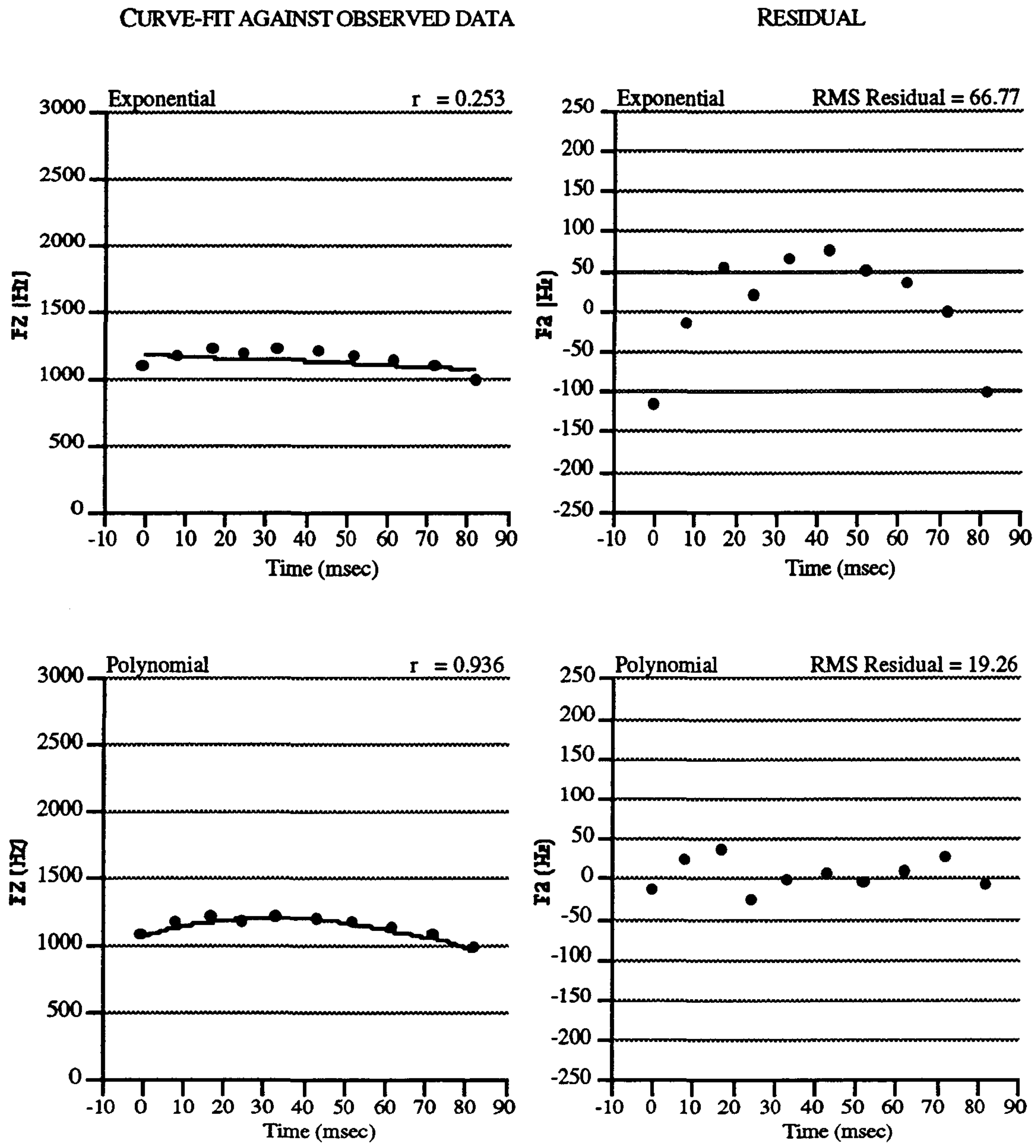


FIGURE 5.3. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE HIGH VOWEL IN THE SYMMETRIC CONTEXT

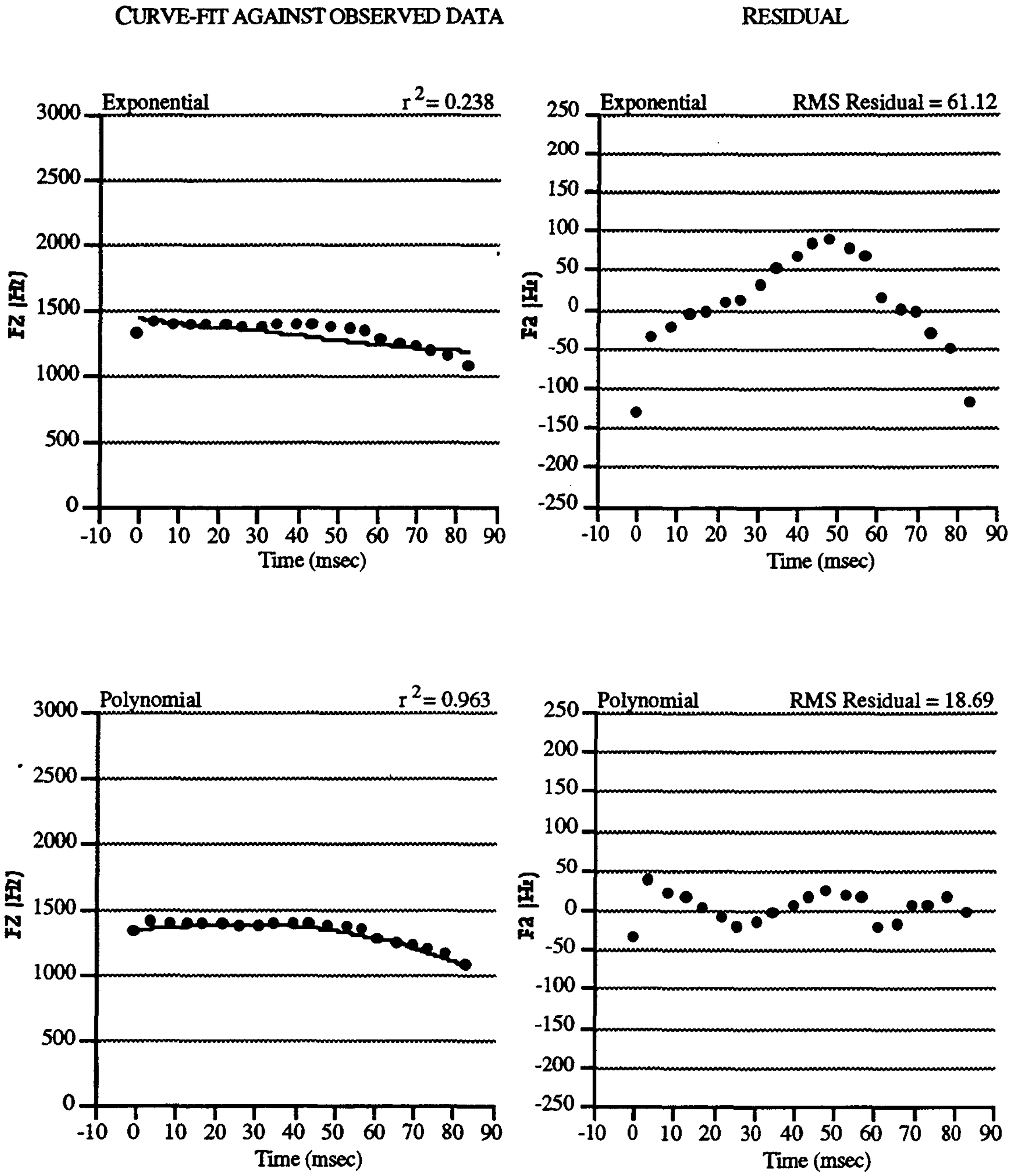


FIGURE 5.4. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE LOW VOWEL IN THE ASYMMETRIC CONTEXT

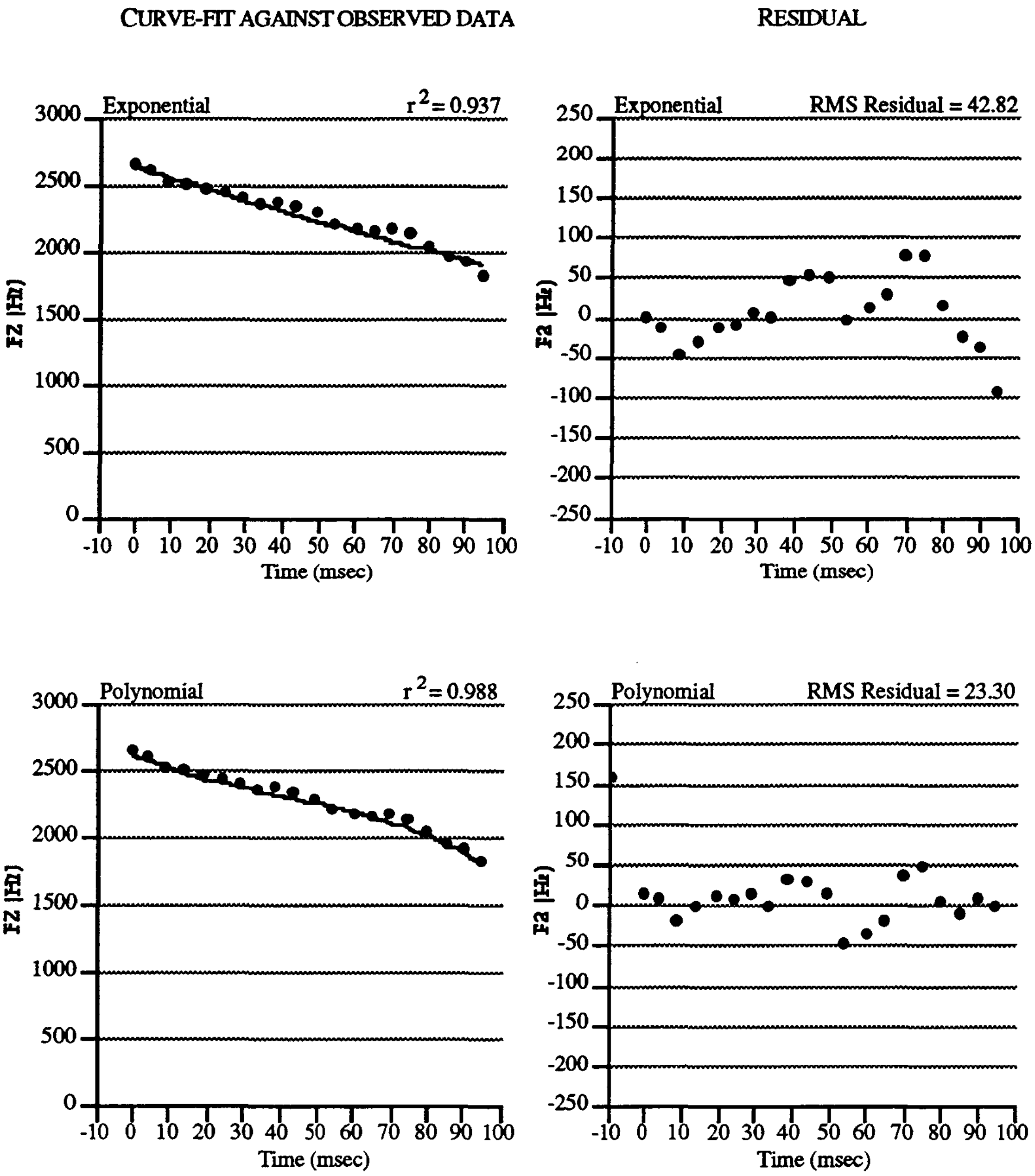


FIGURE 5.5. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE MID VOWEL IN THE ASYMMETRIC CONTEXT

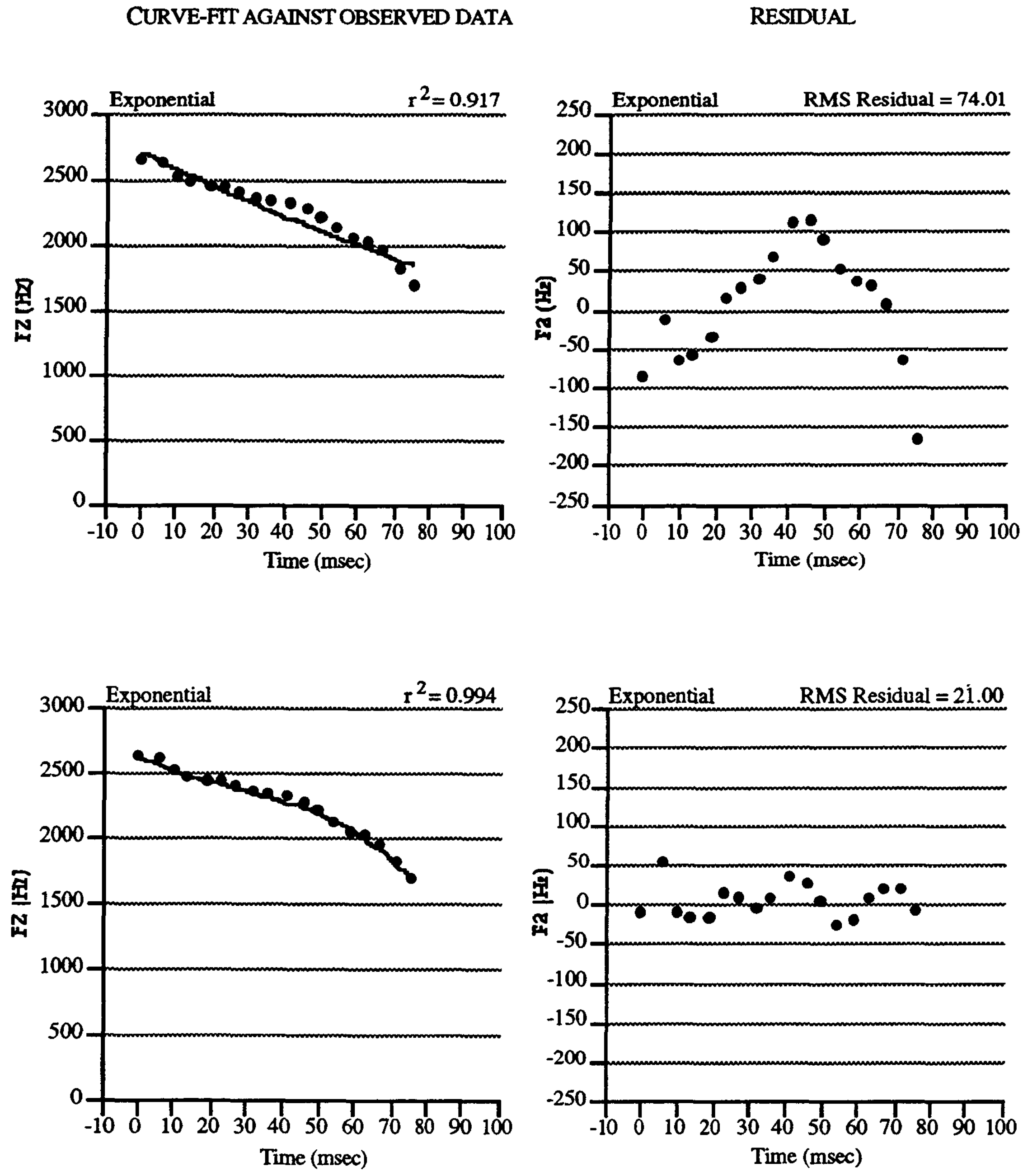
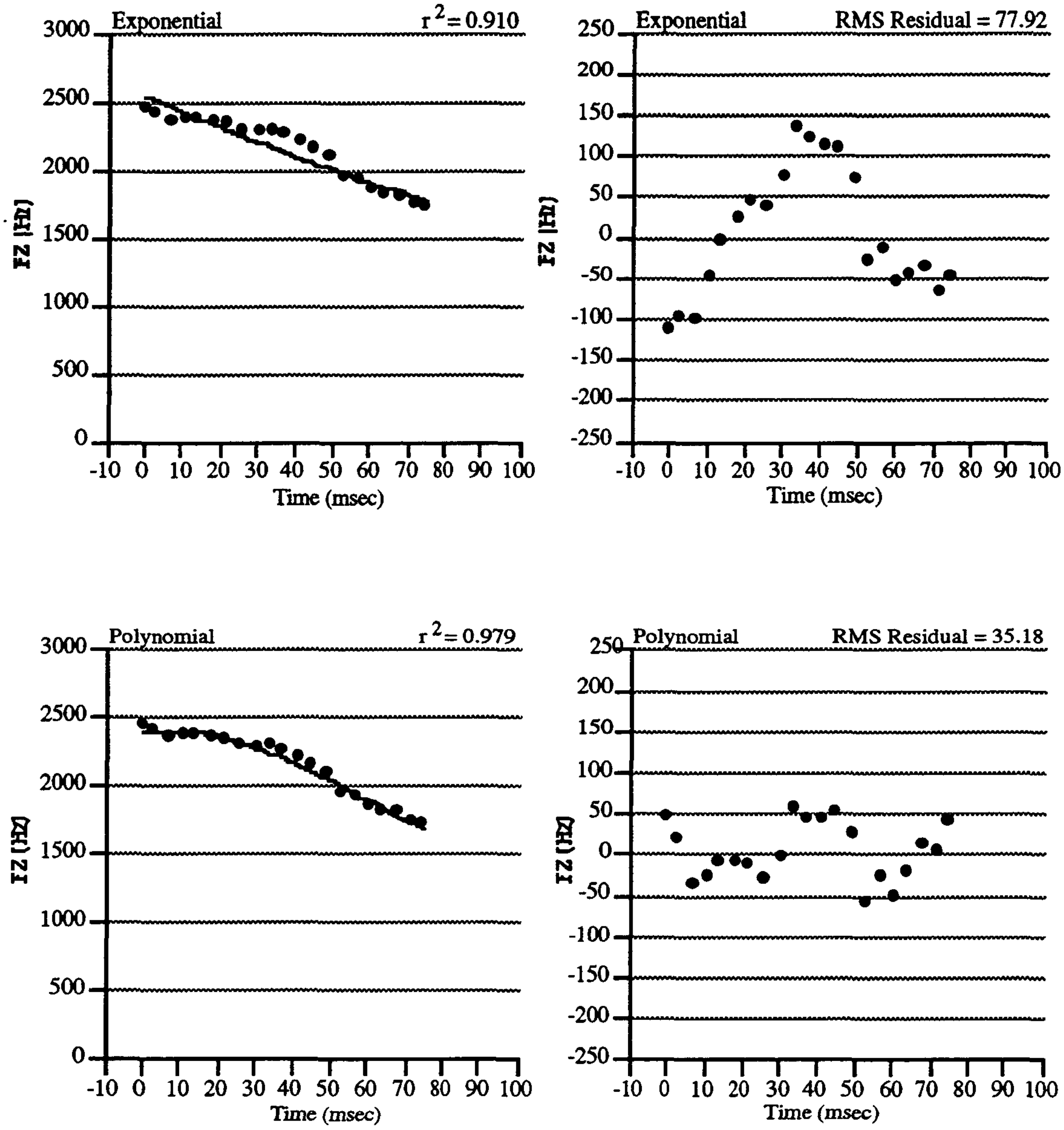


FIGURE 5.6. COMPARISON OF EXPONENTIAL AND POLYNOMIAL CURVE FITS FOR THE HIGH VOWEL IN THE ASYMMETRIC CONTEXT

CURVE-FIT AGAINST OBSERVED DATA

RESIDUAL



5.1.3. DATA REDUCTION AND STATISTICAL DESIGN

Having presented a method for estimating the interpolation function, it remains to define a statistical design with which to assess variation in the trajectories both within and across the experimental factors we have established. Comparison of trajectory shapes proves to be a methodological challenge given the variation in time observed across the repetitions for a given /CVC/ set. A similar problem was confronted in Chapter 3 where multiple regression techniques were applied to assess the relationship between F2 at T_n and F2 at T_{onset} and T_{offset}. Time normalization was used to calculate *n* equidistant time steps for each vowel token for a given normalized time scale of *n*=12 steps. An interpolation function was then used to calculate the F2 value at each T_n, based on the measured F2 values at the nearest real time points. The nature of the model, $F2(T_n) = F2(T_0) + F2(T_{11})$, required an analysis for each of the *n* time normalized points. In so doing, we assessed the linear relationship between $[F2(T_0)+F2(T_{11})]$ and $F2(T_n)$ at the *n*th point in the vowel.

In this chapter, we would like to ask what is the relationship between F2 and time. Assuming a matrix where the column vectors correspond to time and F2, then it follows that if time varies across repetitions and speakers, then we are left with matrices of unequal sizes. This implies that some type of time normalization is required since calculations of variation require matrices of equal size. At the same time, the distortion caused by time normalization becomes a more important consideration than it was in Chapter 3, given the more integral role of time in the model. Ideally, then, time normalization should be avoided.

To eliminate time normalization, it was necessary to redefine the representation of the trajectory so as to accommodate the need for matrices of equal size. This was done by using the curve-fitting procedure as a method of data reduction and by defining each trajectory in terms of a vector consisting of the resulting function coefficients (i.e. $[\alpha_1; \alpha_2; \alpha_3; \beta]$) instead of [F2 x TIME]. Each trajectory and associated vector was then coded for CONTEXT(SYMMETRIC; ASYMMETRIC), VOWEL(HIGH; MID; LOW) and SPEAKER(DY; JG; QJ; TR).

The data were then tested for variation as a function of vowel duration. This was done on the basis of the possibility that the trajectory shapes may differ depending on the duration of the vowel. If this hypothetical covariance is present, then the use of a multivariate analysis of covariance (MANCOVA) model would be warranted. MANCOVA allows us to relate the independent variables of interest to a matrix of the dependent variables and take into consideration any correlation between the dependent variables. In addition, it integrates regression analysis to remove variation in the dependent variable associated with a covariate from the error variance, providing more precise parameter estimates. Duration is specified as a covariate if tests find a relationship between the trajectory shape (as defined by the matrix of dependent variables [α_1; α_2; α_3; β]) and vowel duration. In the absence of such a relationship, a simpler multivariate analysis of variance (MANOVA) model can be used.

The method described permits statistical comparisons across all treatment effects (i.e. CONTEXT, VOWEL and SPEAKER) without relying on time normalization. Since time normalization is eliminated, any distortion associated with it is also avoided. There is, however, an issue that should be kept in mind with the alternative data reduction procedure. While the trajectories are based on real time values, the efficacy of this method is contingent upon the validity of defining the trajectories in terms of the function coefficients. Restated as a question, the issue is as follows: what do these coefficients tell us about the trajectory shape?

The coefficients in a 3rd-order polynomial model each contribute unique properties to the shape of a curve. The β term, or intercept, represents the value of F2 at T_{onset}. A function consisting only of this term would generate a straight line with no slope. The first term, $(\pm)\alpha_1$, represents the slope of the curve. This term can be either positive or negative in value, reflecting the positive or negative slope of the curve. The second term, $(\pm)\alpha_2$, reflects the concavity or convexity of the curve. In describing formant trajectories, the positive or negative value of α_2 can be interpreted as a measure of the direction of displacement from an otherwise linear trajectory. Stevens, et al. (1966) used the curvature values in second order curves to "provide an indirect measure of the relative 'articulatory displacement' between vowel and consonant" (p. 125). The third term, $(\pm)\alpha_3$, is more difficult to interpret, but can be tentatively viewed as a measure of how constant the acceleration is within the curvature defined by α_2. Adjustments to this parameter could, for example, affect the accuracy with which the trajectory reaches the final consonantal target. Bearing these properties in mind, we now turn to the results of the curve-fitting procedure.

5.2. RESULTS

5.2.1. GOODNESS-OF-FIT

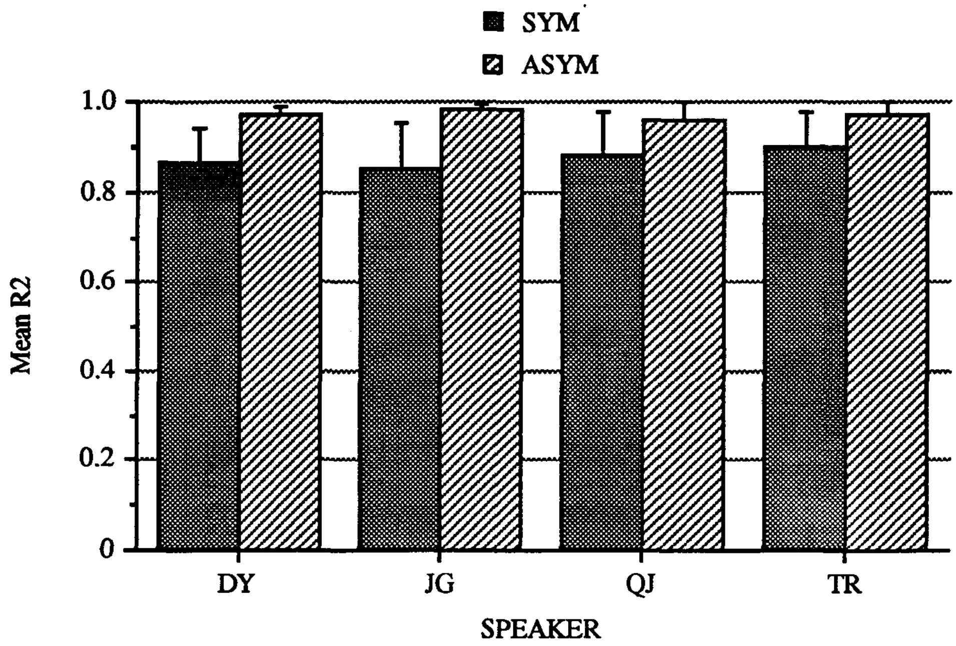
The results of the curve-fitting procedure show that a 3rd-order polynomial function provides greater than 92% fit on average for all the vowels in both secondary articulation contexts (std. dev.=8.3%). A profile of the r^2 values and RMS residual error is presented in Table 5.1 for each set of 10 repetitions.

TABLE 5.1. SUMMARY OF CURVE-FITS

			r^2		RMS RESIDUAL	
SPKR	*CONTEXT*	*VOWEL*	*MEAN*	*STD.DEV.*	*MEAN*	*STD.DEV*
DY	Symmetric	High	0.8777	0.1009	26.9433	6.3258
	Symmetric	Mid	0.8621	0.0643	40.0179	11.7143
	Symmetric	Low	0.8597	0.0665	32.2273	8.9842
	Asymmetric	High	0.9856	0.0074	27.0854	4.2570
	Asymmetric	Mid	0.9753	0.0116	36.7134	7.4122
	Asymmetric	Low	0.9627	0.0157	39.1245	7.8949
JG	Symmetric	High	0.8400	0.0961	30.8667	18.4407
	Symmetric	Mid	0.8671	0.0900	24.8163	12.0606
	Symmetric	Low	0.8472	0.1252	42.8988	18.1424
	Asymmetric	High	0.9895	0.0061	35.1390	13.1366
	Asymmetric	Mid	0.9758	0.0174	45.8004	18.2927
	Asymmetric	Low	0.9865	0.0090	31.5944	8.7931
QJ	Symmetric	High	0.8806	0.0918	33.2305	16.8674
	Symmetric	Mid	0.8951	0.1007	31.7386	20.9296
	Symmetric	Low	0.8742	0.1037	25.3647	15.3539
	Asymmetric	High	0.9516	0.0520	30.1244	17.7448
	Asymmetric	Mid	0.9749	0.0132	26.5949	6.2563
	Asymmetric	Low	0.9571	0.0469	33.3408	20.5751
TR	Symmetric	High	0.8660	0.0810	27.5478	6.1852
	Symmetric	Mid	0.8988	0.0959	24.1060	12.6946
	Symmetric	Low	0.9340	0.0497	23.9140	6.9653
	Asymmetric	High	0.9839	0.0069	28.1218	8.0194
	Asymmetric	Mid	0.9859	0.0092	20.8176	6.8452
	Asymmetric	Low	0.9542	0.0373	28.5829	13.4577

Examination of the r^2 values sorted by context showed that the regression model provided more accurate fits for the trajectories in the asymmetric context than in the symmetric context. Repeated measures analysis of variance on the r^2 values for each curve verified this observation by showing a significant effect for context (CONTEXT: $F_{1,238}=52.30$, $p \leq .0055$). This is illustrated in Figure 5.7 where the mean r^2 is plotted for both the symmetric and asymmetric contexts by speaker. This trend was consistent across all speakers.

FIGURE 5.7. COMPARISON OF GOODNESS-OF-FIT IN FOR THE SYMMETRIC AND ASYMMETRIC CONTEXTS (INDIVIDUAL DATA)



5.2.2. HIGHEST SIGNIFICANT TERM

As noted earlier, the choice of a 3rd-order model was determined on the basis of the assumption that the trajectories exhibited at most two bends - one in the transition out of the initial consonant and another in the transition into the final consonant. However, it was unclear from visual inspection of spectrograms whether or not this generalization held across the entire data set; i.e. it was uncertain if a cubic function would consistently provide significantly better fits than a quadratic function.

To answer this question, the probability scores for the f-values based on the sequential sums of squares (TYPE I) were compared for the cubic, quadratic and linear terms in each model to assess whether or not the addition of that term to the function resulted in a significant reduction in error. Traditionally, parameter comparisons in a polynomial model are made at an α level that is much higher than the standard 0.05 or 0.01 level (Bancroft

1968). For the current study, a level of 0.20 was adopted.

The highest term in the model to significantly increase the goodness-of-fit was designated the highest significant term (HST). A frequency count of HSTs is presented in Table 5.2 for the pooled data. As shown, in 131 out of 240 cases (55%), adding the 3rd term to the model resulted in a significant decrease in error and a corresponding increase in goodness-of-fit. In 90 cases (37.5%), addition of the 3rd term did not result in a significant increase in goodness-of-fit. Neither the 2nd nor 3rd terms significantly improved the fit in 19 cases (7.9%).

TABLE 5.2. FREQUENCY COUNT FOR THE HIGHEST SIGNIFICANT TERM (HST)

HIGHEST SIGNIFICANT TERM	*TOTAL COUNT*	*SYMMETRIC COUNT*	*ASYMMETRIC COUNT*
1	19 (7.9%)	2 (0.8%)	17 (7.1%)
2	90 (37.5%)	53 (22.1%)	37 (15.4%)
3	131 (54.6%)	65 (27.1%)	66 (27.5%)

The cases in which HST<3 combine to make up 45% of the data set. The chi-square score for a contingency analysis conducted for the model [CONTEXT x HST] was significant ($\chi^2_{2,238}$=14.694; p=0.0006), suggesting that CONTEXT and HST were not independent. Closer examination of the contingency tables shows that while the distribution of HST=3 across the two contexts is even, that of HST=2 and HST=1 is not. The distribution of the HST=2 cases was slight skewed toward the symmetric context (59%).

The significant chi-square score, however, is probably attributable to the distribution of the HST=1 results. Virtually all of these cases were associated with the asymmetric context. The proportion of the total variance that is nonlinear in its origin is greater in the symmetric cases. The HST=1 cases constituted 14.2% of the total asymmetric cases examined compared to the 1.7% they represent among the symmetric cases. We conclude, therefore, that the symmetric context is affected more by nonlinearities associated with articulatory sources.

5.2.3. VARIATION AS A FUNCTION OF DURATION

The results of the contingency analysis suggest that the F2 trajectories in the symmetric context can be characterized as requiring a minimum 2nd-order polynomial function while those in the asymmetric context exhibit a greater range of shapes. The question then arises as to whether the variation observed in the HST distribution is associated with variation in vowel duration. It might be the case that the trajectories in the relatively shorter vowels are more linear in shape, while those in the relatively longer vowels are more sinusoidal in shape.

To answer this question, a repeated measures analysis of variance test was run to test for significant variation in duration as a function of SPEAKER and HST. The results showed no significant variation in duration as a function of HST ($F_{2,229}=55.3556$, $p=.1378$). However, the interaction between SPEAKER and HST was significant ($F_{8,232}=4.357$, $p=0.0001$). Mean duration as a function of [SPEAKER x HST] is plotted in Figure 5.8 for the symmetric context and in Figure 5.9 for the asymmetric context.

The data in the symmetric context does show for the one speaker involved (TR) that the linear (HST=1) trajectories are shorter in duration than the HST>1 trajectories. However, it should be pointed out that none of the other speakers exhibited HST=1 trajectories and for the one speaker, the trend is based on only 2 observations of HST=1. There does not seem to be a consistent trend across speakers in the comparison of HST=2 and HST=3 cases.

FIGURE 5.8. MEAN DURATION AS A FUNCTION OF [SPEAKER X HST] IN THE SYMMETRIC CONTEXT

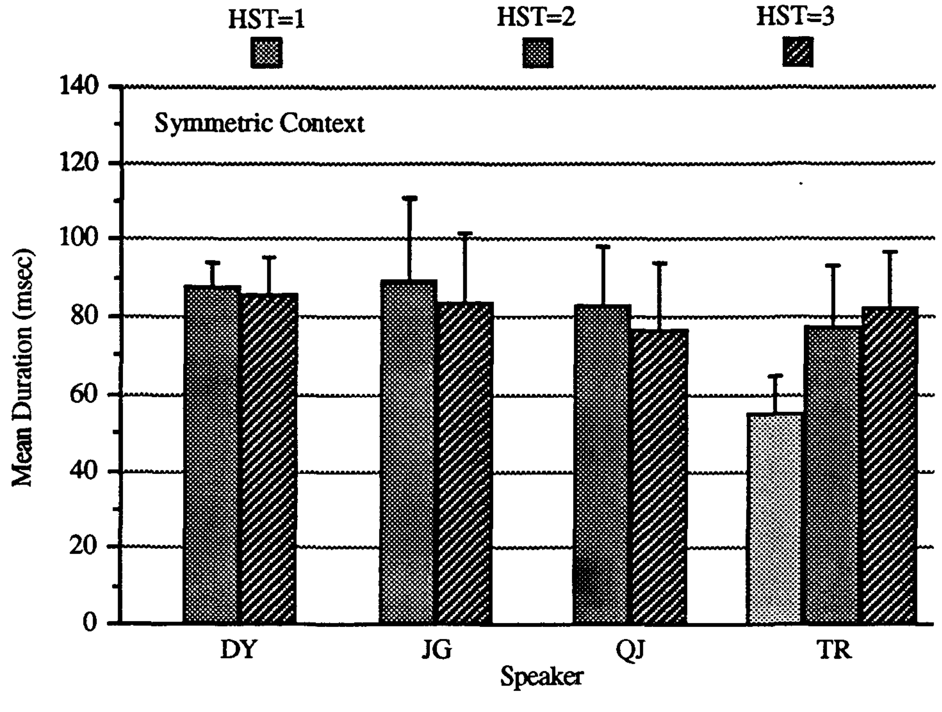
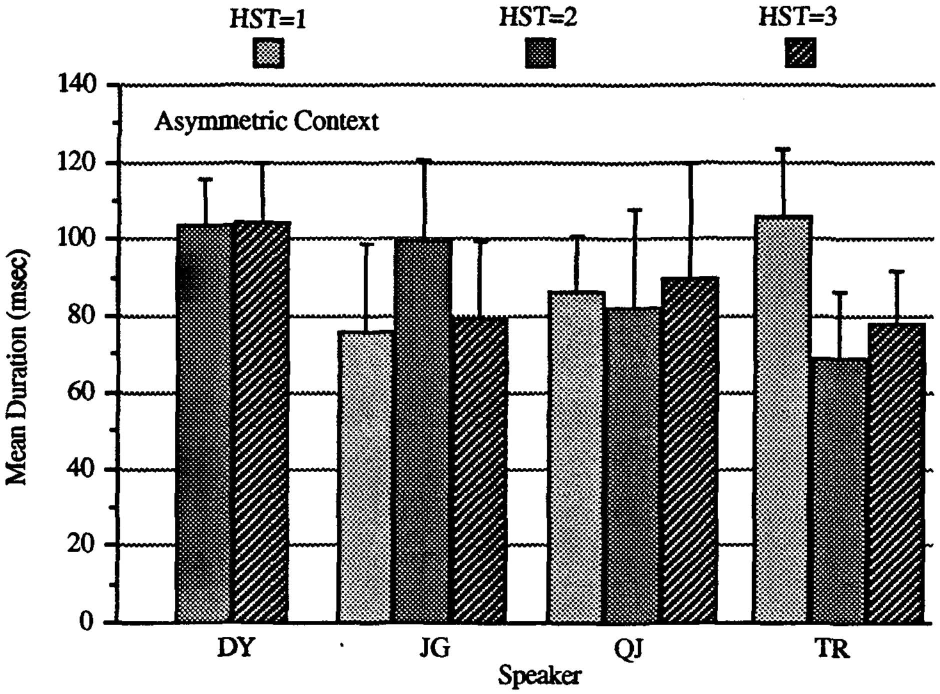


FIGURE 5.9. MEAN DURATION AS A FUNCTION OF [SPEAKER X HST] IN THE ASYMMETRIC CONTEXT



Different trends were exhibited by the speakers in the asymmetric context. So while it is true that the linear trajectories for JG were shorter in duration than her HST=2 trajectories, it is also true that her HST=3 trajectories were also almost as short in duration as her HST=1 trajectories. For TR, the linear trajectories are clearly much longer in duration than his second and third order trajectories.

Given these results, coupled with the unbalanced distribution of the HST categories in the comparison, it is concluded that there is no significant variation in HST as a function of vowel duration. This does not preclude the possibility, however, that there might be a correlation between duration and the individual terms in the curve function. It might be the case that the first and second terms (representing slope and convexity, respectively) may be lower in symmetric trajectories when the vowels are shorter.

To test this hypothesis, the four terms [α_1; α_2; α_3; β] were tested for correlation with duration. The results, summarized in Table 5.3, shows that there is no correlation between any of the individual terms and duration. These results are taken as evidence that there is no consistent variation in the trajectory shape, as defined by [α_1; α_2; α_3; β] or by HST, as a function of duration. It should be further noted that this lack of correlation justifies the use of MANOVA in analyzing the within/between category variation as opposed to MANCOVA.

TABLE 5.3. SUMMARY OF r^2 SCORES FOR THE CORRELATION ANALYSIS BETWEEN THE VECTOR ELEMENTS AND DURATION

MODEL	r^2
Intercept x Duration	0.0307
α_1 x Duration	0.0181
α_2 x Duration	0.1820
α_3 x Duration	0.0028

5.2.4. CORRELATION BETWEEN TERMS

While there was a lack of correlation between any of the terms and duration, some of the terms did exhibit correlation between themselves. The intercept and α_1 exhibited a negative partial correlation coefficient of -0.5550 ($p=0.0001$). This relationship is illustrated in Figure 5.10. The correlation was expected and can be explained by the fact that the intercept term patterns with context: a lower intercept, corresponding to secondary velarization, is observed in the symmetric context while a higher intercept, corresponding to secondary palatalization, is observed in the asymmetric context. Thus, it is not surprising that we find that the lower intercept terms co-occur with higher (zero or positive) α_1 values, while the higher intercept terms co-occur with the lower (negative) α_1 values.

It is interesting to note that the intercepts corresponding to secondary velarization form a much tighter cluster than those associated with secondary palatalization. This contrast harks back to the results of the contingency analysis which showed that the trajectories in the symmetric context were more restricted in their shape (in so far as they required a minimum 2nd-order function) while the trajectories in the asymmetric context varied with respect to the HST in the function.

A strong negative partial correlation coefficient (-0.8854) was also found between α_1 and α_2 ($p=.0001$). This relationship is illustrated in Figure 5.11 which shows that lower α_1 values tended to co-occur with higher α_2 values. Stated in other terms, the trajectories in the symmetric context (low α_1) exhibited more convexity than those in the asymmetric context (high α_1).

FIGURE 5.10. CORRELATION BETWEEN INTERCEPT AND α_1

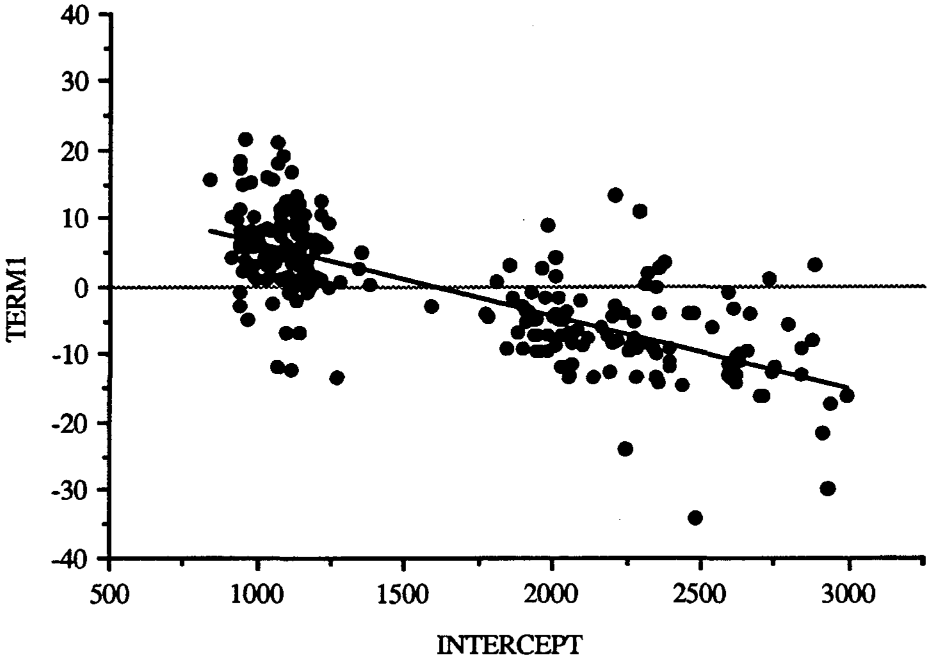
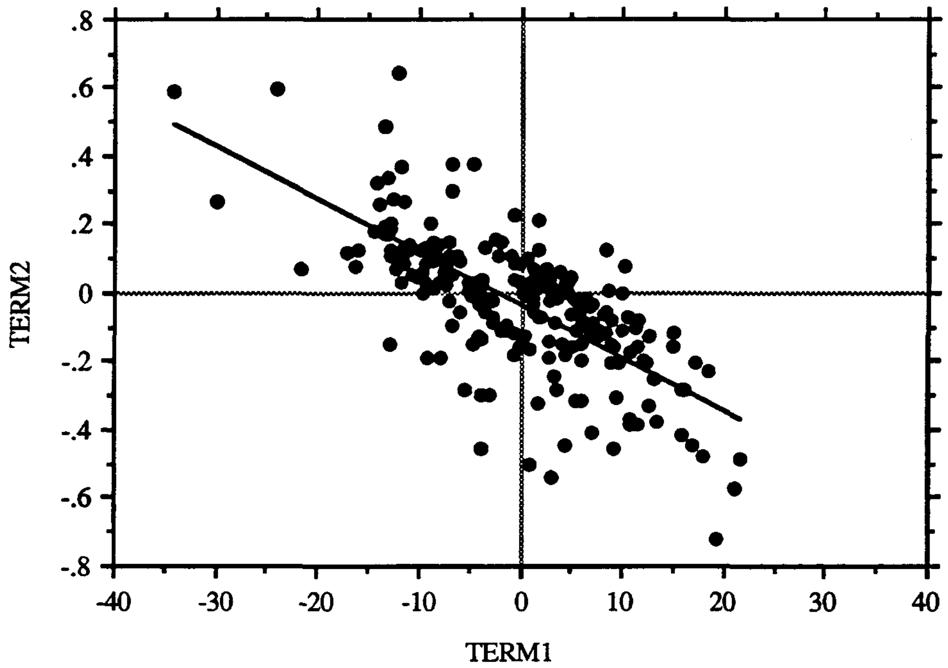


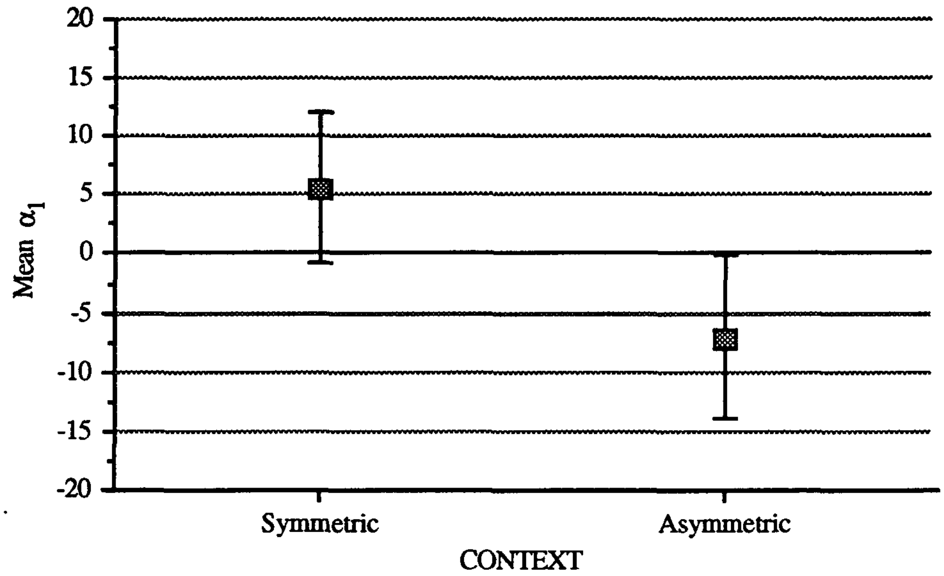
FIGURE 5.11. CORRELATION BETWEEN α_1 AND α_2



5.2.5. VARIATION IN THE COEFFICIENTS AS A FUNCTION OF CONTEXT, VOWEL CATEGORY AND SPEAKER

Given the strong association between the intercept and context, the MANOVA test was run on the vectors [α_1; α_2; α_3] alone. A preliminary analysis based on [α_1; α_2; α_3; β] found that the contribution of the intercept in defining contextual variation was so strong that its inclusion in the model made the contribution of the three coefficients nearly invisible. At the same time, it is these terms that provide the greatest information regarding the trajectory shape.. Therefore, the discussion here will focus on a model without the intercept term.

FIGURE 5.12. MEAN α_1 AS A FUNCTION OF CONTEXT



Beginning with the pooled data, the repeated measures MANOVA tests show a significant effect of CONTEXT (based on the Wilks criterion) on trajectory shape (CONTEXT: $F_{1,238}$=273.8482; p=0.0001). The F-value for VOWEL was much lower in comparison to CONTEXT, but nonetheless significant (VOWEL: $F_{2,237}$=2.5124; p=0.0212).

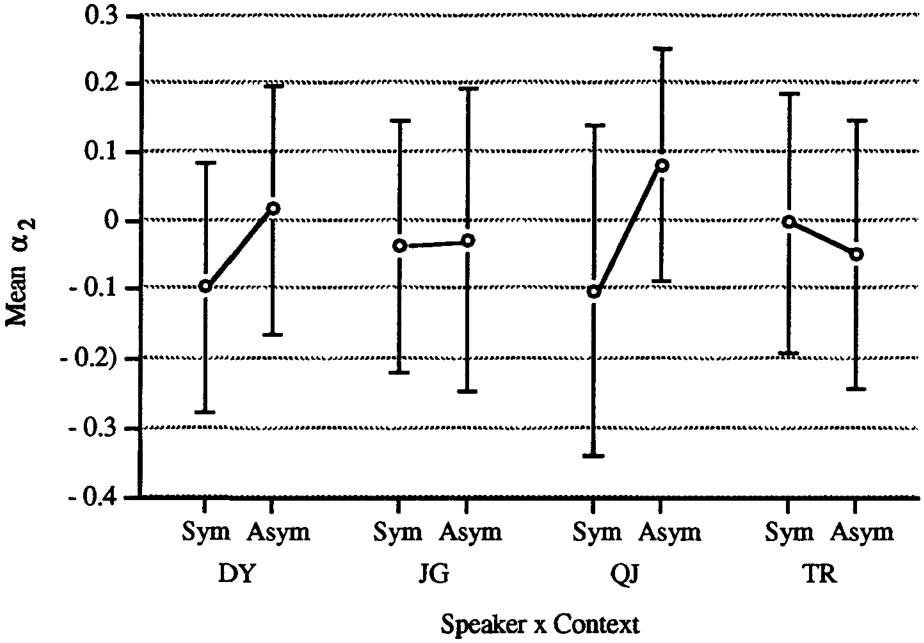
To localize the sources of these effects, the data were also submitted to repeated measures univariate tests. These results show that only the effect of CONTEXT on α_1 was significant (CONTEXT: $F_{1,238}$=58.85; p=0.0046), a relationship for which we saw evidence in the correlation analyses discussed in section 5.2.4. We conclude, therefore, that the primary source of variation in trajectory shapes is attributed to α_1, and that this variation is a function of context.

The repeated measures MANOVA tests also showed significant differences across SPEAKERS. To confirm that the conclusion drawn from the pooled data could be generalized across the speakers, univariate tests were run separately on each speaker. The results are summarized in Table 5.4; only significant results are reported.

TABLE 5.4. SUMMARY OF THE ANOVA RESULTS BY SPEAKER (SIGNIFICANT RESULTS ONLY)

		α_1		α_2		α_3	
SPKR	*EFFECT*	*F*	*P*	*F*	*P*	*F*	*P*
DY	CONTEXT	61.37	0.0001	5.92	0.0183		
JG	CONTEXT	94.41	0.0001				
	VOWEL	3.33	0.0432				
QJ	CONTEXT	68.03	0.0001	12.19	0.0010		
TR	CONTEXT	29.11	0.0001			6.92	0.0111

FIGURE 5.13. MEAN α_2 AS A FUNCTION OF [SPEAKER x CONTEXT]



All the speakers exhibited highly significant effects on α_1 by CONTEXT, confirming that the conclusion drawn from the pooled data analysis obtains for each speaker. Two of the speakers, however, also exhibited significant effects on α_2 as a function of CONTEXT. This relationship is illustrated in Figure 5.13 for all of the speakers. As shown, the effect is in the same direction in the two speakers for whom the effect is significant: α_2 is higher in mean value in the asymmetric context than in the symmetric context. We find different trends in the two other speakers. For JG, while it is true that the same directionality obtains, there is virtually no difference in the means. For TR, the relationship exists in the opposite direction; i.e. the mean α_2 is lower in the asymmetric context than in the symmetric. This variation across the speakers accounts for why context did not show up as a significant effect on α_2 in the pooled data.

5.2.6. CANONICAL INTERPOLATION FUNCTION

Having examined the relationships between the terms in the functions and those between the independent variables and the terms, it remains to define an "average" trajectory Φ for the two contexts. A priori, the function defining Φ should be of the 3rd order. This is motivated by the fact that while 45% of the trajectories examined could be modeled with $\text{HST} \leq 2$, a 3rd order function was required to capture all of the data.

Accordingly, Φ was estimated by calculating the mean of each function. We initially considered basing the canonical function on only those models in which HST=3 (n=65 for the symmetric context; n=66 for the asymmetric context) on the assumption that if we were constructing a 3rd-order model, then we should include only those functions in which addition of the 3rd-term significantly improved the goodness-of-fit. However, we decided that inclusion of the model coefficients in the subset of the data where HST<3 would provide a more faithful representation of the trends observed in the contingency analysis.

TABLE 5.5. DURATION CHARACTERISTICS FOR /p^{ɣ}Vp^{ɣ}/ AND /t^{j}Vt^{ɣ}/ (POOLED DATA)

VOWEL	*COUNT*	*MEAN*	*STD. DEV.*	*STD. ERROR*
HIGH	80	.072	.014	.002
MID	80	.086	.014	.002
LOW	80	.105	.015	.002

In addition to defining two separate canonical functions associated with each of the two contexts, it was also decided to define a function for each of the vowels. The need for this further division comes from the differences in duration associated with the three vowel categories. Repeated measures analysis of variance found the variation in duration as a function of vowel category to be significant (VOW: $F_{2,237}=47.504$, $p \leq 0.0002$). The variance within each category, summarized in Table 5.5 and Figure 5.14, is consistent as evidenced by the standard deviations. However, variation within a single standard deviation represents very different proportions for each vowel: e.g., in the case of the high vowel, one standard deviation represents 19% of the mean while that in the low vowel only represents 14% of the mean.

Variation across speakers was also considered and found to be significant (SPKR: $F_{3,236}=13.069$, $p \leq 0.0001$). Closer examination of speaker variation, summarized in Table 5.6, found that while the standard deviations are not as consistent within and between the speakers across the three vowel categories, the overall trend can be said to be reflected in the 0.014 to 0.015 seconds range seen in the pooled data. It was also the case that the general trend in duration differences across the vowel categories obtained for all the speakers (Figure 5.15), although there were slight differences in the magnitude of these differences.

Given the significant variation in duration across vowel categories, the canonical interpolation functions were defined on three different time scales, based on the pooled mean durations for each vowel. The mean values for each of the four terms in the function were then calculated and the resulting function was plotted. The results are presented on a fixed time scale of 120 msec for the asymmetric context in Figure 5.16 and for the symmetric context in Figure 5.17.

FIGURE 5.14. DURATION PROFILE (POOLED DATA)

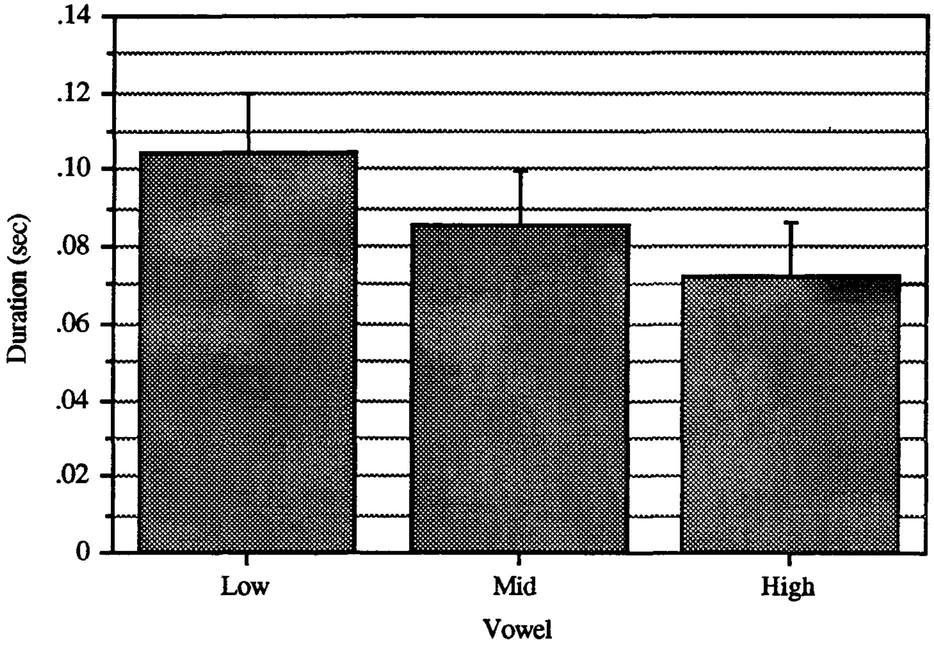


FIGURE 5.15. DURATION PROFILE FOR [SPEAKER x VOWEL]

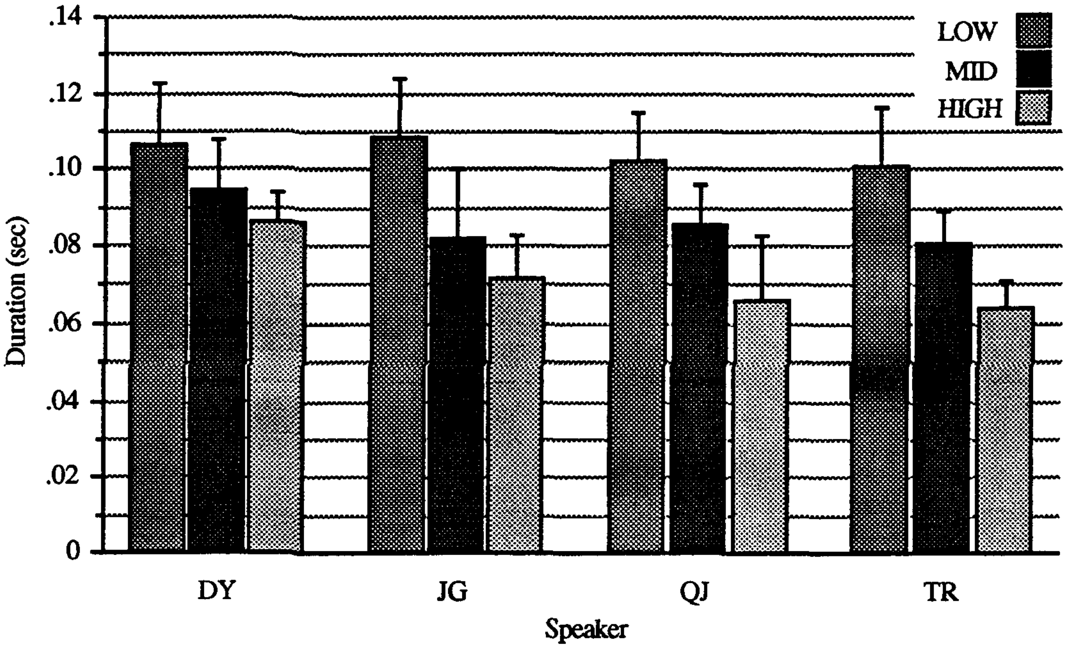


TABLE 5.6. DURATION CHARACTERISTICS FOR [SPEAKER x VOWEL]

	VOWEL	*N*	*MEAN (SEC)*	*STD. DEV.*	*STD. ERROR*
DY	LOW	20	.107	.016	.004
	MID	20	.095	.013	.003
	HIGH	20	.087	.007	.002
JG	LOW	20	.109	.015	.003
	MID	20	.082	.018	.004
	HIGH	20	.072	.011	.002
QJ	LOW	20	.102	.012	.003
	MID	20	.086	.010	.002
	HIGH	20	.066	.016	.004
TR	LOW	20	.101	.016	.003
	MID	20	.081	.008	.002
	HIGH	20	.064	.007	.002

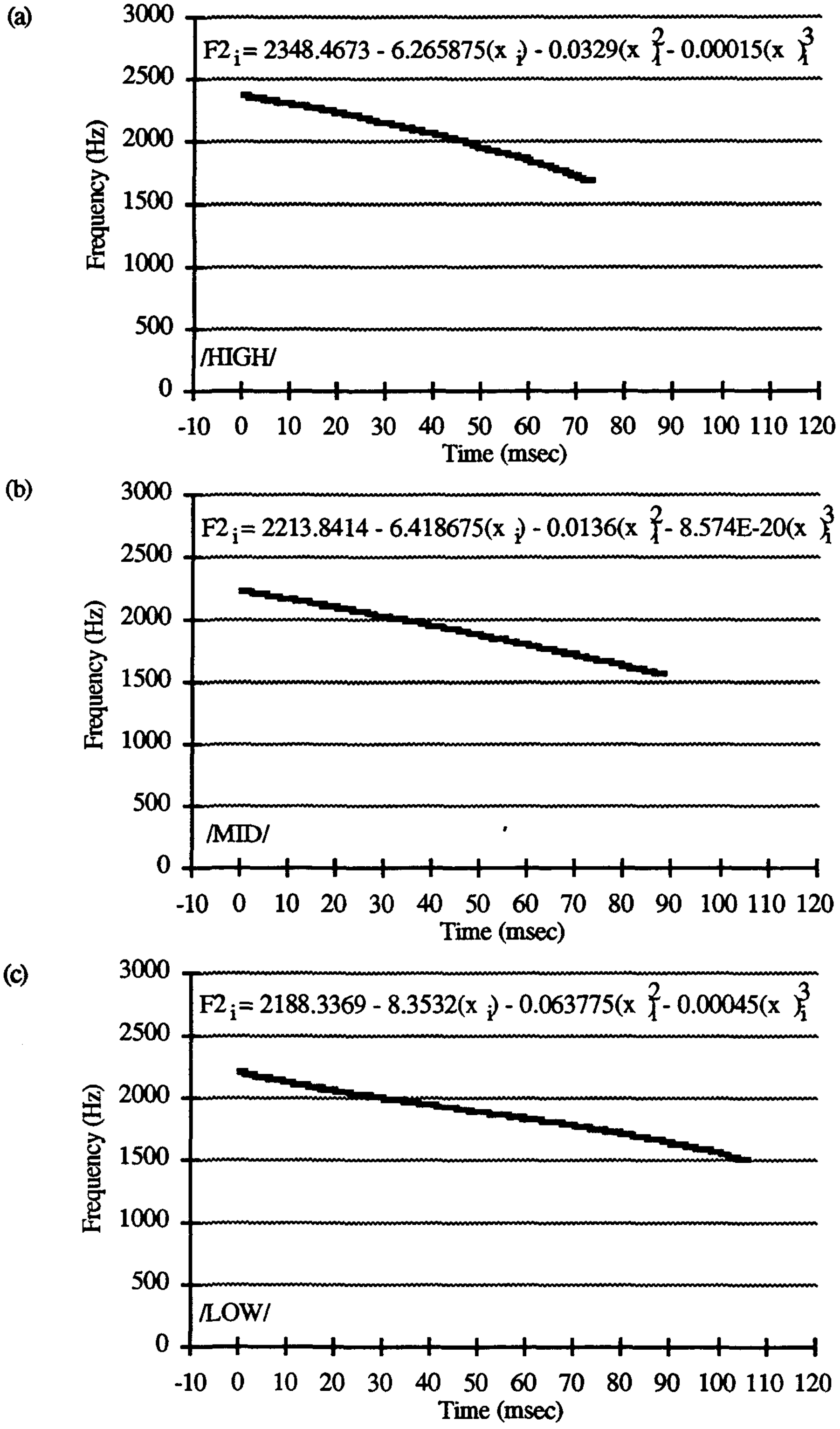


FIGURE 5.16. MEAN TRAJECTORIES IN THE ASYMMETRIC CONTEXT

FIGURE 5.17. MEAN TRAJECTORIES IN THE SYMMETRIC CONTEXT

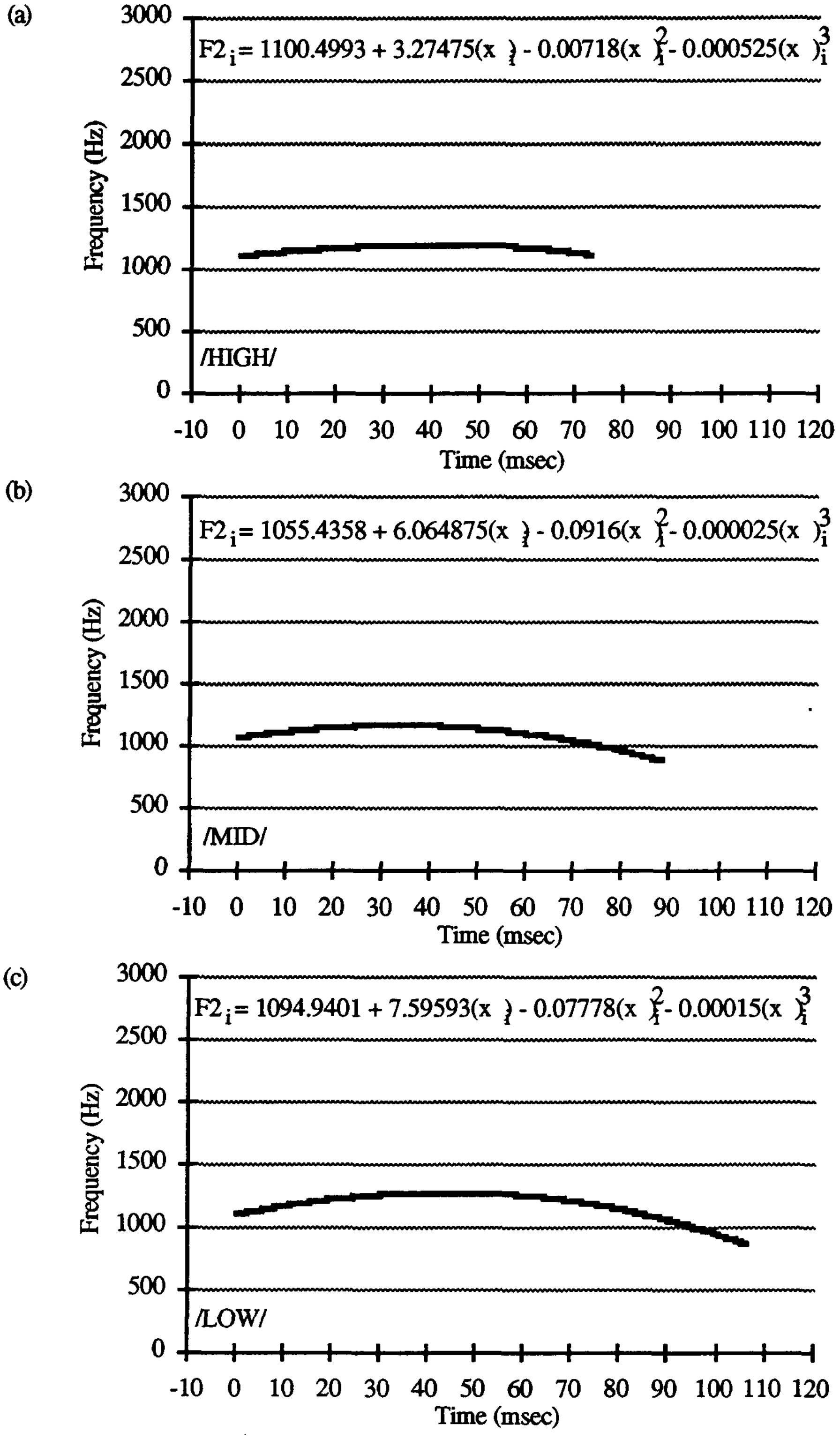
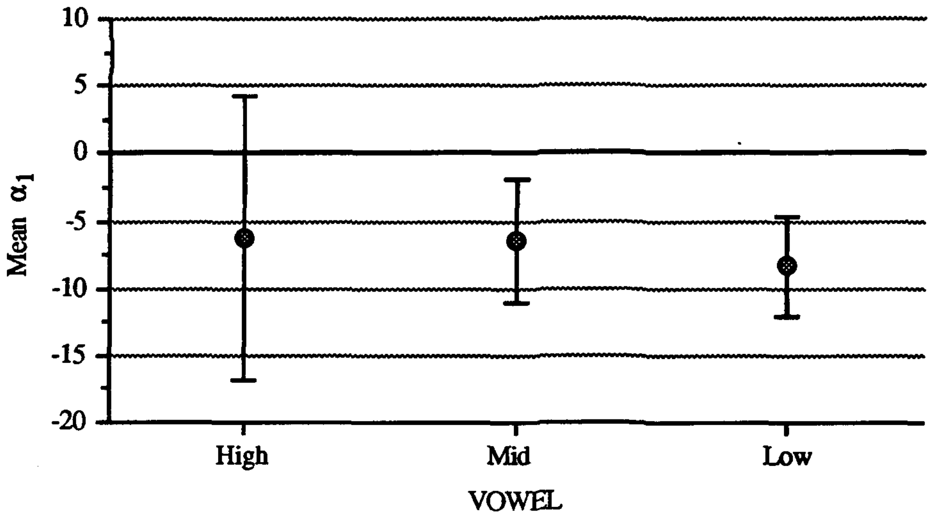


FIGURE 5.18. MEAN α_1 IN THE SYMMETRIC CONTEXT



The three trajectories in the asymmetric context do not differ, but the same cannot be said for those in the symmetric context where the lower vowels exhibit trajectories with increasing curvature. Analysis of variance found that α_1 differed significantly as a function of vowel category in the symmetric context (VOW: $F_{2,118}=5.130$, $p=0.0074$). Comparison of means, illustrated in Figure 5.18, shows this effect to be strongest in the /LOW/ vowel. The /MID/ vowel is also slightly lower than the /HIGH/ vowel with respect to their mean α_1 values, however, this difference was not found to be significant in post-hoc tests. α_2 was found to stay relatively constant across the three vowel categories. Given the relatively constant α_2, then we would expect to see increasing convexity as α_1 increased with increasing vocalic aperture.

5.3. DISCUSSION

The results of the trajectory modeling study show that the interpolation function governing movement from the initial secondary articulation target to the final secondary articulation target is better defined in terms of a polynomial function than an exponential function. It is the case that in greater than half of the trajectories examined, addition of a third term to the polynomial function resulted in a significant increase in the goodness-of-fit. In only a very small subset of the data examined did a function of the first order (i.e. linear) prove statistically adequate. Descriptively, then, we *must reject the hypothesis that* the interpolation function in Marshallese /CVC/ syllables is linear. Theoretically, however, it may still be the case that the interpolation function from C_1 to C_2, is in effect linear in character. Arguments supporting this supposition, based on (i) the weight of α_3 and (ii) the effect of primary place of articulation, are now considered.

5.3.1. CONTRIBUTION OF A_3

While it was observed that α_3 contributed to a statistically significant increase in goodness-of-fit in greater than half the trajectories examined, it is far from clear that this statistically significant increase also results in a linguistically significant contribution. It is difficult to define "linguistically significant" in the context of trajectory shapes. One could attempt to define it in terms of perception: i.e., would a native speaker of Marshallese judge F2 trajectories generated by a 3rd-order polynomial function to be more natural or more intelligible than those generated by a 2nd-order or even 1st-order function? 'tHart (1991) found that listeners do not perceptually distinguish linear approximations of fundamental frequency contours from parabolic approximations, although the original F0 curves were parabolic in shape. It is not clear that this result would generalize cross-linguistically, much less to the segmental domain, and is an area for future research that would provide an interesting test with which to evaluate the conclusions drawn from this study.

FIGURE 5.19. COMPARISON OF A 3RD-ORDER AND 2ND-ORDER POLYNOMIAL TRAJECTORY FOR THE ASYMMETRIC CONTEXT

$$F2 = 2250.215175 - 7.012583333(x_i) + 0.005775(x_i)^2 - 0.0002(x_i)^3$$

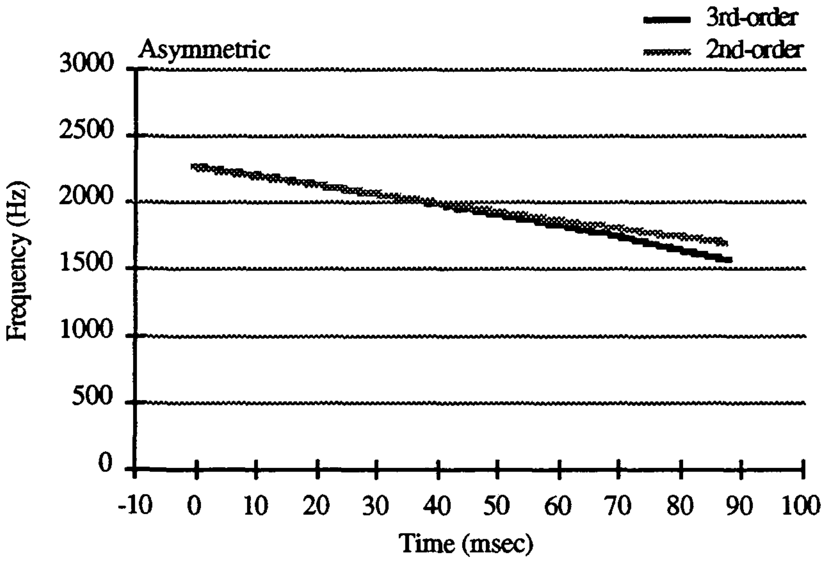
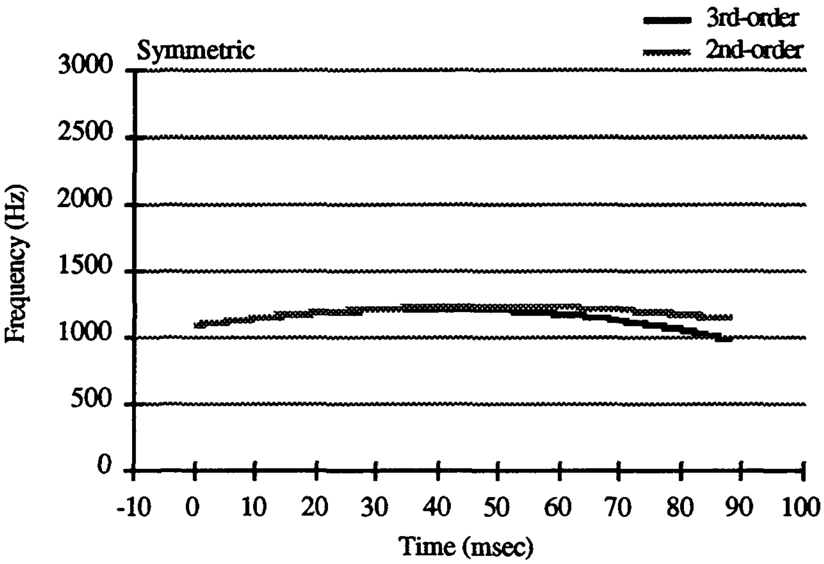


FIGURE 5.20. COMPARISON OF A 3RD-ORDER AND 2ND-ORDER POLYNOMIAL TRAJECTORY FOR THE SYMMETRIC CONTEXT

$$F2 = 1083.624942 + 5.64518333(x_i) - 0.05885(x_i)^2 - 0.00023(x_i)^3$$



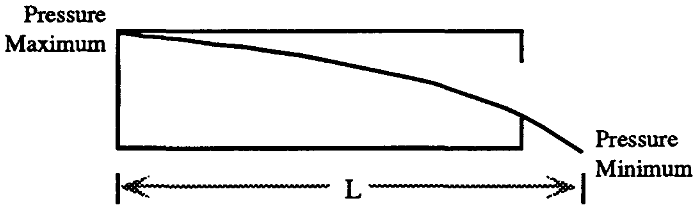
In lieu of a perceptual study, the contribution of α_3 was examined more closely in defining the shape of the trajectory by calculating the mean coefficient values for each context (i.e. collapsed across all vowels) and generating two curves, one with three terms and one with two terms, using the mean duration for the pooled data. This is presented in Figures 5.19 and 5.20. By keeping the first and second terms fixed, the effect of α_3 could be isolated.

As the comparisons show, the 3rd term contributes very little in altering the basic shape of the trajectory, which is primarily defined by α_1 and α_2. The low values for α_3 suggest that the rate of change is relatively constant, and there is some slight deceleration to adjust for the final target, as evidenced by the negative values for α_3. Although difficult to interpret, these observations could be taken as evidence showing that the minor adjustments reflected in α_3 tend to compensate for potential overshoot. What is evident, however, is that α_3 contributes very little in altering the shape of the trajectory. This, along with the fact that the addition of α_3 did not result in a significant increase in goodness-of-fit in almost half the trajectories examined, brings into question the necessity of the third term in generating the trajectory course from C_1 to C_2.

5.3.2. *DIFFERENCES IN CONVEXITY ACROSS CONTEXT*

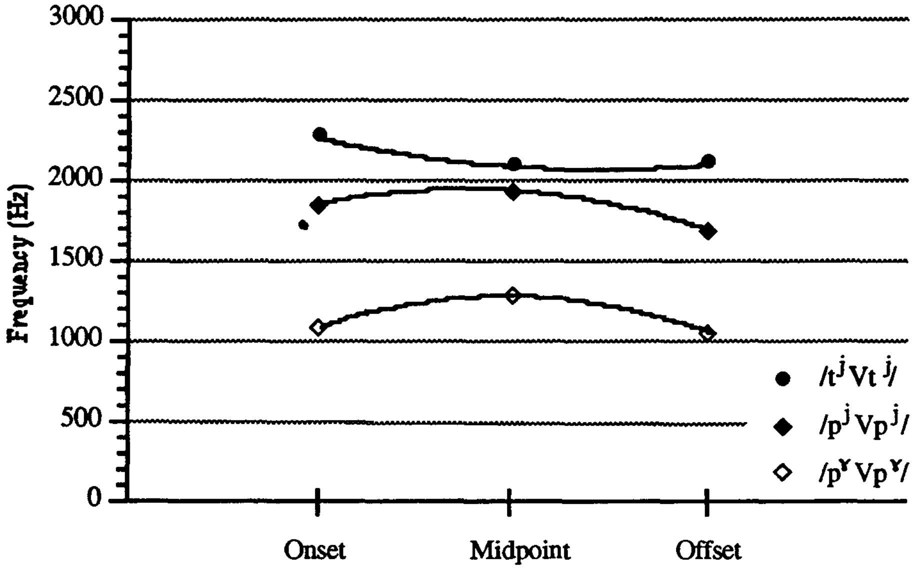
We observed that the mean F2 trajectory in the asymmetric context was essentially linear in character. The same could not be said of the trajectories in the symmetric context, which exhibited greater convexity with respect to the horizontal axis. The difference in F2 trajectories in the symmetric and asymmetric contexts found in Marshallese parallel those that Pierrehumbert (1980) found in English intonation. In her framework, separate interpolation functions are used in different contexts; a linear function is used to govern interpolation from L to H, while a sagging interpolation function is used to move from H to H. The Marshallese data could be handled in a similar manner by making the choice of the F2 interpolation function contingent upon an evaluation procedure which has access to the C_1 and C_2 values. This strategy has also been implemented in text-to-speech systems (Allen, et al. 1987). However, while this solution produces the desired results, it provides no explanation for the differences observed. Why is it, then, that we see the trends that we do?

FIGURE 5.21. EFFECTS OF CONSTRICTION AT THE LIPS IN A UNIFORM TUBE MODEL



An explanation stems from considerations regarding primary place of articulation. Primary place was not controlled across the two contexts due to gaps in the data set; the symmetric context consisted of bilabials while the asymmetric context consisted of alveolars. It may be the case then, that the curvature we observe in the symmetric context is due to bilabial closure. The curvature is consistent with what we would expect to see as a result of closure at the lips. Consider the vocal tract as a uniform tube, where narrowing of the lip aperture is modeled as a constriction at the open end of the tube, as illustrated in Figure 5.21. The resulting increase in the air pressure behind the constriction would effectively shift the pressure minimum to a point outside the tube. Given that the formant frequencies F_k can be estimated by the equation $F_k=(2k-1)c/4L$, an increase in L would produce a lower F_k.

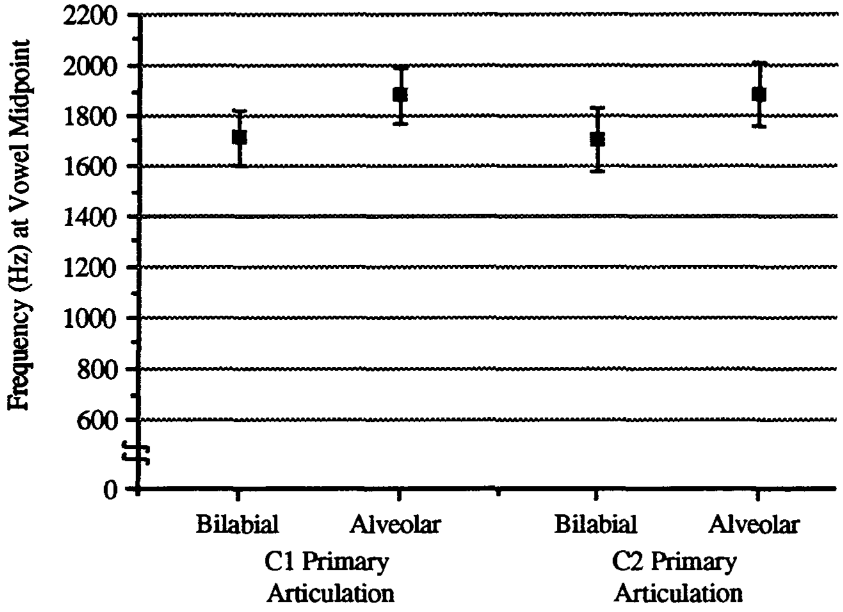
FIGURE 5.22. COMPARISON OF CURVATURE IN PALATALIZED BILABIAL AND PALATALIZED ALVEOLAR CONTEXTS FOR THE /LOW/ VOWEL (POOLED DATA)



A comparison of the trajectories in the /pˠVpˠ/ versus /tˠVtˠ/ contexts would provide evidence for this hypothesis. If we found no comparable curvature in the /tˠVtˠ/ tokens, then we could conclude that primary place of articulation was in fact responsible for the observed convexity in the F2 trajectory in /pˠVpˠ/. Unfortunately, dictionary searches and native speaker consultation failed to produce monosyllabic /tˠVtˠ/ lexical items to include in the word list. The corpus did include, however, the contrast /pʲɐpʲ/ 'coconut frond' and /tʲɐtʲ/ 'snapper fish' in which vowel height and secondary articulation are kept constant. The mean F2 values at the three time points T_{onset}, T_{mid} and T_{offset} were calculated for these two lexical items and are plotted in Figure 5.22. The mean F2 values are also plotted for /pˠɐpˠ/ 'fit tightly'. The idealized F2 trajectories were generated by 3rd-order polynomial functions fitted on the three points. Comparison of the two bilabial series shows that the effect of primary place of articulation is consistent across both secondary articulations. When the palatalized bilabial and palatalized alveolar series are compared, we observe a contrast. Both series exhibit some curvature, but the direction is different; /pʲɐpʲ/ exhibits an F2 trajectory that is convex with respect to the horizontal axis while /tʲɐtʲ/ exhibits an F2 trajectory that is concave with respect to the horizontal axis. The degree of curvature is also greater in the bilabial context than in the alveolar context. These differences suggest that effects of primary place of articulation do account for the differences in curvature observed in the symmetric and asymmetric contexts.

There were results reported in Chapter 3, reproduced here in Figure 5.23, which lend further support to the primary place of articulation account. The effects of primary place of articulation were found to persist into the middle of the vowel ([C1P]: $F_{1,1158}=25.944$, $p \leq 0.0146$; [C2P]: $F_{1,1158}=61.247$, $p \leq 0.0043$). However, these mean values do not include any /$t^{ɣ}$V$t^{ɣ}$/ tokens, which we predict would have lowered the means and possibly diminished, if not eliminated, this effect.

FIGURE 5.23. EFFECTS OF PRIMARY PLACE OF ARTICULATION ON F2 AT THE VOWEL MIDPOINT (POOLED DATA)



Symmetry with respect to secondary place of articulation offers another possible explanation with which to account for the difference in convexity across the two contexts. The asymmetric context involved articulatory movement from one secondary constriction site (the palatal region) to another distinct secondary constriction site (the velar region). We hypothesize that this movement involves a relatively smooth sliding motion which is roughly parallel to the palate. This is illustrated in the idealized mid-sagittal view in Figure 5.24, where the secondary constriction sites are represented as points in a two dimensional space. Movement between palatalized and velarized consonants, labeled (c), is influenced by the articulatory demands associated with the positioning of the tongue dorsum required to produce the necessary vowel height contrasts. In so far as movement from C_1 to C_2 involves anterior-posterior adjustments while vowel production requires high-low adjustments, these articulatory demands are antagonistic.

In the symmetric context, we might posit that the vertical adjustments required for vowel production are accompanied by horizontal displacement as well. This is illustrated by the articulatory path labeled (b) in Figure 5.24. If movement occurs along a slanted plane, then F2 will be affected. Alternatively, we could posit that there is no movement along the anterior-posterior dimension and the lingual adjustments required to produce the height contrasts are constrained to a vertical plane fixed with respect to the secondary constriction site, as illustrated by (a) in Figure 5.24. Vertical displacement, as we have already discussed in terms of differences in cross-sectional area, is also predicted to result in a perturbation in F2. In principle, then, both (a) and (b) could account for the increase in curvature observed in the /LOW/ vowel /pˠVpˠ/ tokens. There have been numerous studies (Meyer 1910; Russell 1928, 1936; Ladefoged 1962; Harshman, et al. 1977; Wood 1975, 1979, 1982; Jackson 1988) which have shown that the traditional description of vowels in terms of high-low and front-back (Bell 1967) is not supported by articulatory data, suggesting that the path illustrated in (a) is probably unrealized. However, both accounts remain speculative and require articulatory data for verification.

FIGURE 5.24. HYPOTHETICAL PATHS OF MOVEMENT IN ASYMMETRIC AND SYMMETRIC SECONDARY PLACE OF ARTICULATION CONTEXTS

We have proposed that the observed asymmetries in the F2 trajectory shape in the /pˠVpˠ/ versus /tʲVtˠ/ contexts can be attributed to either (i) primary place of articulation effects associated with bilabial closure and the resulting lowering in formant frequencies, or (ii) the relative freedom of the tongue body to move along the vertical dimension in symmetric secondary articulation contexts. Quite probably, both factors are involved. There is nothing in the analysis which could, in principle, decide whether symmetry itself or primary place of articulation is responsible for the differences in convexity observed in the data. A more complete characterization of the interpolation function would require a deeper and more systematic understanding of the articulatory system and the interaction of multiple effects.

CHAPTER 6: CONCLUSIONS

The data examined in this dissertation corroborate Bender's (1968) observations regarding the short vowels of Marshallese and support his impression that vowel quality in asymmetric environments is determined by competing consonantal influences. Acoustic analysis shows that the surface allophones can be described as fronted/palatalized and backed/velarized in symmetrically palatalized and velarized consonantal environments, respectively. In asymmetric consonantal contexts, the vowels can be described as diphthongal or dynamic in character. The particular diphthongal qualities that appear in the asymmetric environments are consistent and can be predicted based on the consonants surrounding the vowel.

6.1. THE UNDERSPECIFICATION HYPOTHESIS

The restricted distribution of the vowels in Marshallese was argued to fall out from phonetic underspecification and interpolation between targets. F1 was found to be an inherent property of the vowel, and this was taken as evidence for an underlying vocalic height contrast. F2, however, was found to be determined by the surrounding consonants and modeled in terms of movement from a C_1 F2 target to a C_2 F2 target without reference to a vocalic F2 target. The consonantal F2 targets are posited as being projected from their respective primary and secondary articulation features. The effects of the secondary articulation features were found to be dominant in determining F2 in the vowel. Explicit in this hypothesis is the claim that the vowels in Marshallese /CVC/ syllables are underspecified along the front/back dimension.

TABLE 6.1. SUMMARY OF THE RESULTS

- $F2_{T_{mid}} = f(C_1 \times C_2)$
- $F2_{T_{mid}} = f(\text{Vowel Height})$
- $F2_{T_n} = f(F2_{T_0} + F2_{T_{11}})$
- C-to-C coarticulation

The predictions made by this account are borne out in the acoustic data and were verified by statistical methods. F2 at the vowel midpoint was found to vary primarily as a function of consonantal secondary articulation type. While there was a weak effect on F2 associated with vowel category, this was attributed to variation in constriction size (i.e. the phonemic vowel height contrast) and not to an inherent front/back vocalic specification. The data also showed robust consonant-to-consonant coarticulation, providing further evidence that the vowels lack a F2 target. These results, summarized in Table 6.1, all suggest that the vowels of Marshallese can be modeled without reference to an F2 target in the underspecification paradigm.[†]

A theory positing fully specified vowel representations at the phonetic level would have to carry the burden of identifying the F2 target. It would be problematic to estimate such a target given the results of this acoustic study. Rephrased from the standpoint of learnability, how would the child learn that there is a front/back distinction in the vowel system if there is no evidence for it in the acoustic signal? There was simply no positive evidence for a vocalic F2 target in the /CVC/ lexical items examined.

6.2. CONSONANTAL LOCUS ASYMMETRIES

The data examined in this study also revealed several asymmetries relating to the initial and final consonants. First, we saw that carryover coarticulation was stronger in magnitude than anticipatory coarticulation for the female speakers, and that the male speakers exhibited carryover and anticipatory coarticulation with relatively equal magnitude. It was never the case that anticipatory coarticulation exceeded that of carryover.

Examination of F2 at the vowel peripheries also revealed asymmetries in the consonantal loci in onset and offset positions. The mean values associated with primary place of articulation differed depending on syllable position by a magnitude difference of 179 Hz for the alveolars and 197 Hz for the labials on average. In all cases, the offset values were lower than the onset values. An asymmetry was also observed for secondary palatalization, but not for velarization. This was localized to /p^j/ which showed a much lower locus in the offset position (magnitude difference of 368 Hz).

Asymmetries associated with syllable position have been reported in numerous articulatory studies (Houde 1968; Kent & Moll 1972b; Munhall et al. 1991), which have shown that the tongue body moves in an elliptical path out of and into the consonants in /CVC/ syllables. While these studies have been based on English, the explanations offered

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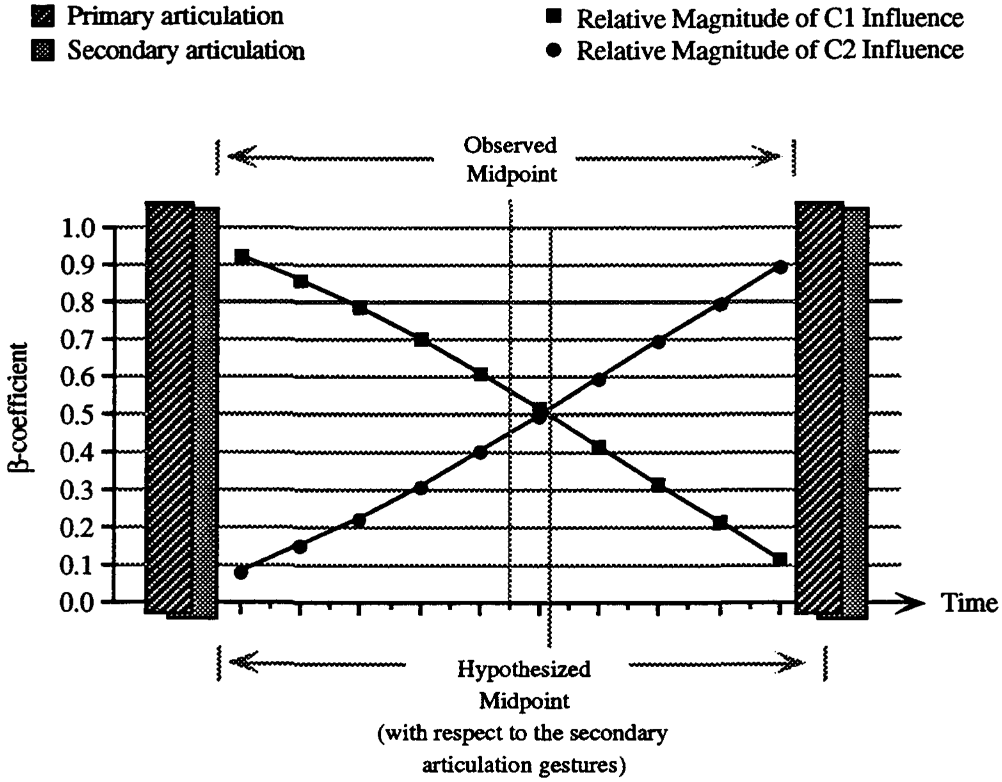
[†] The operators [x] and [+] in Table 6.1 reflect the statistical models involved in the respective results; i.e., [C1xC2] stands for the interaction between C1 and C2, and [$F2T_0+F2T_{11}$] is taken directly from the regression model. The operators are not meant to express explicit claims on the combinatorial nature of the acoustic model, so that $f(x * y)$ should be read as "...a function involving some combination of the factors x and y."

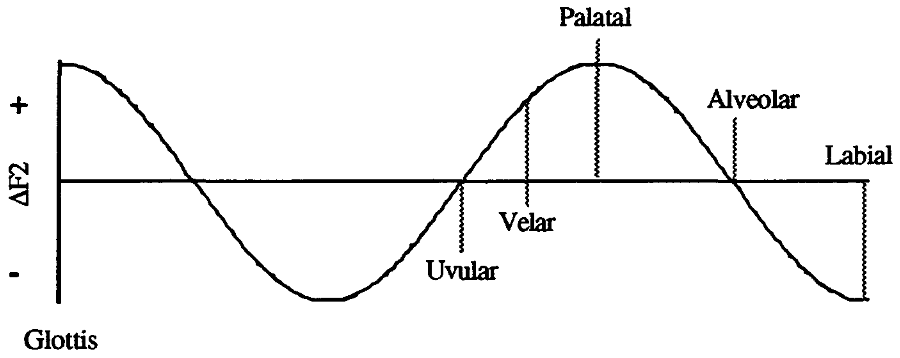
appeal to physiological-mechanical considerations, and by implication, apply cross-linguistically. For example, Kent & Moll (1972b) have hypothesized that the asymmetries are due to aerodynamic factors. There is a greater build-up in air pressure in the production of the initial consonant, implying a forward movement at release. In the production of the final consonant, the pressure in the oral cavity has equalized to atmosphere during vowel production so that the constriction in C_2 would not be subject to the same aerodynamic pressures as C_1. This account seems to be a plausible explanation for the differences in primary place of articulation, but it is far from clear that it can be extended to account for the differences associated with secondary place of articulation as well since the secondary constrictions are made without complete closure, allowing equalization across the two cavities.

FIGURE 6.1. HYPOTHETICAL ASYNCHRONOUS TIMING OF THE PRIMARY AND SECONDARY ARTICULATIONS AND THE RESULTING ACOUSTIC CONSEQUENCES



A more likely explanation comes from potential differences in articulatory timing associated with the primary and secondary articulations. Ladefoged (1993: 230) states that "...a secondary articulation is ... an articulation with a lesser degree of closure occurring at the same time as another (primary) articulation". It may be the case, however, that the timing of the primary and secondary articulation is not exactly simultaneous, and that one articulation may be slightly offset with respect to the other.* Consider Figure 6.1 where this is represented in terms of the dark and lighter bars, representing primary and secondary articulation, respectively. The secondary articulation has been timed slightly later than the primary, and is represented by the offsetting of the two bars. This representation has been superimposed on the results of the standardized z-score tests reported in Chapter 3 (c.f. Figure 3.20). Estimates based on the pooled data (cf. Figure 3.19) suggest that the offset is, on average, approximately 28° out of phase. This estimate was calculated by comparing ratios: i.e. $(0.7 / 9.0) = (x^{\circ} / 360^{\circ})$, where $(0.7 / 9.0)$ is the ratio of the difference between the crossover point and the observed midpoint (=0.7) in Figure 6.1 and the number of normalized time steps in the vowel (=9.0). The proposed difference in timing associated with the primary and secondary articulations would also explain why the cross-over point for the relative influence of C_1 and C_2 comes slightly later in the vowel than the observed (i.e. acoustic) midpoint. If F2 in the vowel is primarily a function of secondary articulation, then we would expect the time course of the C_1 and C_2 effects to reflect the offset of the secondary articulation gestures.

FIGURE 6.2. EFFECT ON F2 RELATIVE TO A UNIFORM TUBE (AFTER STEVENS (IN PREP))



The hypothetical offset of the secondary articulation with respect to the primary articulation would have acoustic consequences. Namely, the effects of the secondary articulation on the spectral characteristics observed at the vowel onset would be stronger

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* Evidence for the non-simultaneity of gestures in complex consonants has been reported by Maddieson (1992) for the doubly-articulated labial-velar consonants in Ewe. Maddieson's articulatory data show that these consonants are not produced with simultaneous labial and velar closure, but rather that the velar gesture slightly precedes the labial gesture. A more complex asymmetry in the timing of complex gestures has also been documented by Maddieson (1991) for Pohnpeian labio-velarized consonants. Examination of F2 at the vowel midpoint shows that while both the labial and velar gestures perseverate from the initial consonant, only velarization is anticipated from the final consonant.

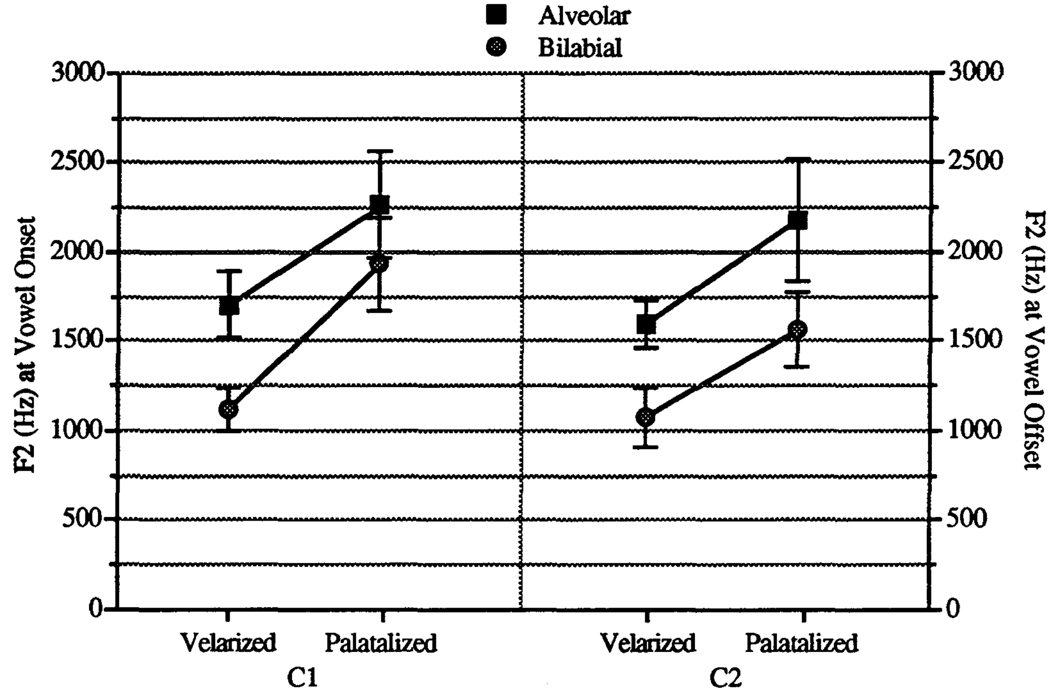
than at the offset. At the vowel offset, the effects of primary place of articulation would be stronger than those associated with the secondary place of articulation. Therefore, we would not expect the observed F2 values to be the same in onset and offset position.

The proposed account does not, by itself, account for the greater asymmetry in the /pʲ/ locus in onset and coda position since the timing between the primary and secondary constrictions would apply equally in both positions. The difference in timing between the primary and secondary articulations is only half of the story. The other half has to do with the effects on F2 associated with constriction at the labial, alveolar, palatal and velar sites (Stevens 1972, IN PREP; Fant 1973; Fant & Pauli 1974; Mrayati, et al. 1988). These effects are illustrated in Figure 6.2, where the relative change in F2 (ΔF2) is plotted as a function of distance from the glottis for a uniform tube. We posit that constriction in the alveolar region is relatively neutral with respect to its effects on F2 (although it may be slightly forward of the crossover point; cf. Bender's description of this series as dental in Chapter 2). Constriction in the labial region, on the other hand, will lower F2. Narrowing in the palatal region produces exactly the opposite effect of narrowing in the labial region since it is at a pressure maximum; i.e., constriction in the labial and palatal regions produces effects on F2 that are maximally dissimilar. Velar constriction also differs from labial constriction in its effect on F2. However, this difference is not as strong as it is for the palatal versus labial effects.

Given these effects, it follows that we would expect to see the greatest asymmetry in consonantal loci for /pʲ/. Since the effects of the secondary constriction will be stronger at the vowel onset due to the relative timing of the primary and secondary articulations, we would expect a relatively higher F2 associated with the secondary palatal constriction, while at the vowel offset, we would expect a relatively lower F2 associated with the primary labial constriction. For /pˠ/, the difference in F2 in the two positions would not be as strong, given the smaller magnitude difference between the effects on F2 associated with velar and labial constrictions. When the primary constriction is in the alveolar region, we should not expect differences in initial and final position if the effect is relatively neutral. However, significant differences were found, suggesting that the primary alveolar constriction may be further from the glottis than represented in Figure 6.2.

It should be observed that despite the differences in absolute mean F2 values for the consonants across the two syllable positions, sufficient acoustic/perceptual distance is maintained, as illustrated in Figure 6.3 for the four consonants in initial and final position. The contrasts in primary place of articulation are not rendered ambiguous, nor are those for secondary place of articulation.

FIGURE 6.3. ACOUSTIC DISTANCE FOR EACH OF THE CONSONANT PAIRS IN INITIAL AND FINAL POSITION



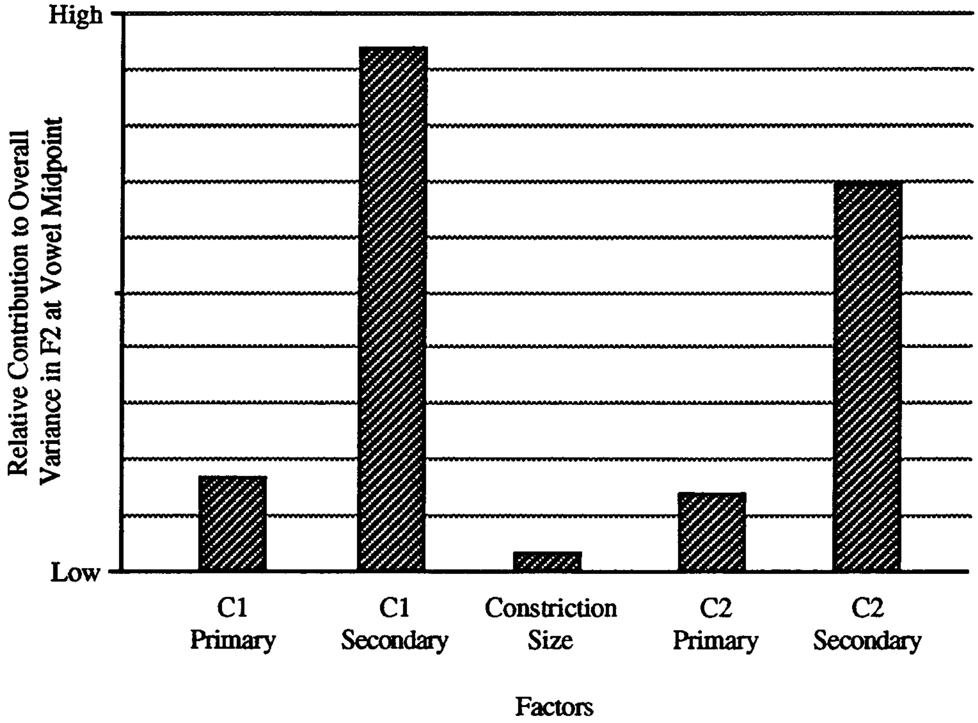
6.3. DIFFERENCES IN CURVATURE ACROSS CONTEXTS

The lack of a vocalic F2 target associated with an inherent front/back specification also allowed for an easily observable and durationally substantial transition phase with which to investigate the movement from one target to another. The characterization of these trajectories, based on a least-squares polynomial regression model, showed that the F2 trajectories differed in their degree of convexity depending on the consonantal context. In the asymmetric context $/C^jVC^\gamma/$, a linear interpolation function was found to provide an adequate fit to the F2 trajectory. In the symmetric context $/C^\gamma VC^\gamma/$, the trajectory shape was found to be much more parabolic. This curvature was attributed to the effects of narrowing at the lips (i.e. primary articulation) which causes a lowering in the formant patterns. We speculate that if this was factored out, then we would find that the interpolation function for movement from secondary articulation to secondary articulation is roughly linear for both contexts examined. The F2 function, then, consists of a linear component attributed to the effects of secondary constriction, and a nonlinear component attributed to the effects of primary constriction.

6.4. *THE MODEL*

The hypothesis testing in Chapter 3 and the descriptive study in Chapter 5, then, have revealed a set of factors, listed in Table 6.2, which contribute to determining phonetic vowel quality in Marshallese /CVC/ strings. The relative weight of the factors at the vowel midpoint is illustrated in Figure 6.4 (adapted from Figure 3.7). It has been shown that the magnitude of effects associated with each factor changes with time, so that the weight of constriction size associated with vowel height is greatest at the vowel midpoint, but is virtually null at the vowel peripheries (cf. Figure 3.18), and the effects of C_1 and C_2 decrease as we approach offset and onset position, respectively (cf. Figure 3.20).

FIGURE 6.4. RELATIVE CONTRIBUTION OF THE FACTORS AT THE VOWEL MIDPOINT (POOLED DATA)



Each of these factors has been discussed in turn, but we have not yet explicitly provided a derivational model based on these factors. In this section, we step back from the complexities involved in the interpretation of the acoustic data and propose a simple (idealized) model which qualitatively captures the general trends observed in the data.

TABLE 6.2. COMPONENTS OF THE MODEL

- Primary place of articulation
- Secondary place of articulation
- Constriction related to vowel height

- Relative timing of primary & secondary articulation
- Relative timing of secondary articulation & vowel height
- Relative timing of C_1 and C_2

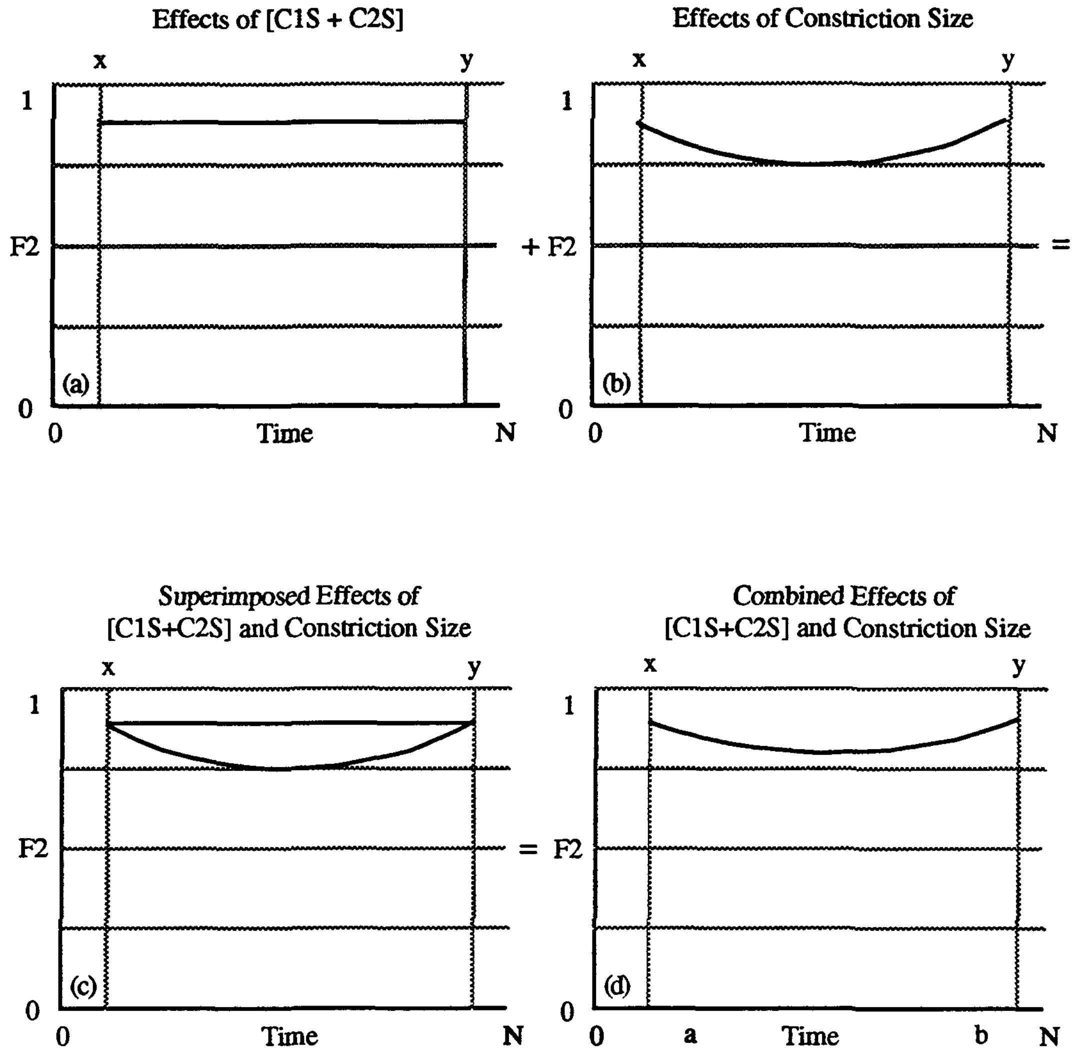
The F2 contour is defined in terms of (1):

$$F_{C_1VC_2}(n) = f(S_{C_1}(n) x S_{C_2}(n)) \bullet f(P_{C_1}(n) x P_{C_2}(n)) \qquad (1)$$

where $f(S_{C_1}(n) x S_{C_2}(n))$ defines the secondary articulation effects and $f(P_{C_1}(n) x P_{C_2}(n))$ defines the primary articulations effects. The exact nature in which these effects combine is left undefined, and is denoted by the operator (•). As in Table 6.1, the (x) operator is defined as denoting an interaction, and not a literal multiplicative relationship.

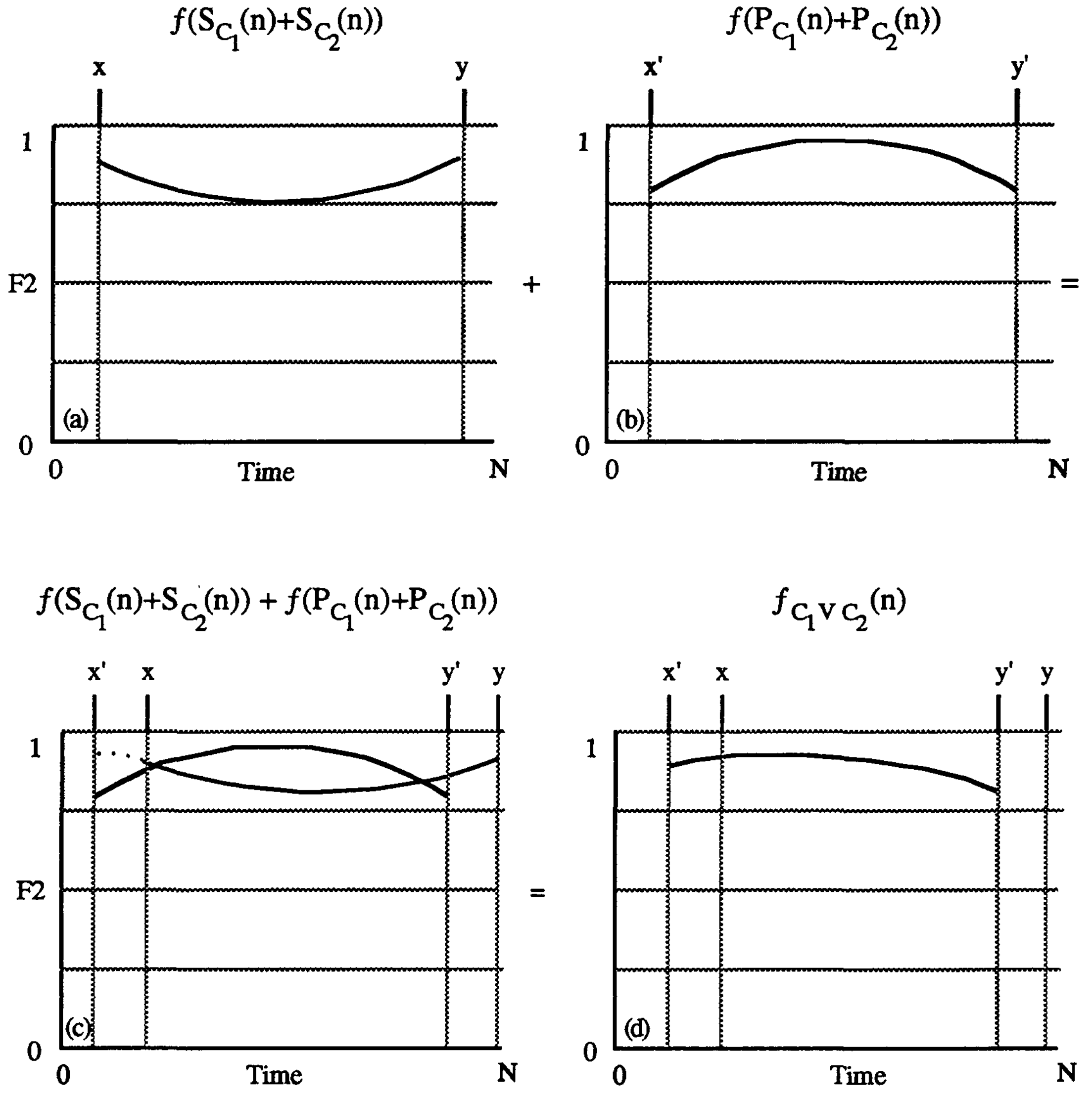
The function $f(S_{C_1}(n) x S_{C_2}(n))$ representing the contribution of the secondary constriction can be further broken down into two components, one associated with the secondary articulations alone and one associated with the effects of constriction size (cf. Figure 2.6). This is graphically represented in Figure 6.5 for the symmetrically palatalized context. The effects of the peripheral secondary place of articulation targets (Figure 6.5a) are taken to be relatively monotonic, assuming a linear interpolation function. The variation in F2 associated with vowel height is represented as a function that is concave with respect to the horizontal axis (Figure 6.5b). The concavity or convexity of this function is determined by the secondary constriction site (cf. Figure 2.6 and Figure 3.8); in the palatal region, an increase in constriction size is predicted to result in a lowering of F2, whereas in the velar region, narrowing of constriction is predicted to increase F2. Functions (a) and (b) are superimposed in Figure 6.5c and the resulting function is represented in Figure 6.5d. It is important to note that the effect of constriction size is timed with respect to the secondary articulation effects. This follows from the physiological fact that both involve the same articulator, and from their common phonological affiliation with backness.

FIGURE 6.5. COMPONENTS OF $f(\mathrm{S_{C_1}(n)xS_{C_2}(n)})$



The interaction between $f(\mathrm{S_{C_1}(n)xS_{C_2}(n)})$ and the primary articulation function $f(\mathrm{P_{C_1}(n)xP_{C_2}(n)})$ is illustrated in Figure 6.6 for the symmetric /$\mathrm{p^jVp^j}$/ context. The trajectory in Figure 6.6a represents $f(\mathrm{S_{C_1}(n)xS_{C_2}(n)})$ (cf. Figure 6.5d). The contribution of primary articulation, $f(\mathrm{P_{C_1}(n)xP_{C_2}(n)})$, is represented in Figure 6.6b. As already discussed, a narrowing in the labial region results in a lowering of all the formants, hence the effects of a symmetric /pVp/ context is represented as a convex function. It could be argued that since labial transitions are typically very quick, the primary articulation function should not affect the entire vowel and should perhaps exhibit a plateau. However, given the short duration of the vowels being modeled, it is proposed that the effects of the labial transitions, though quick, cover most of the vowel.

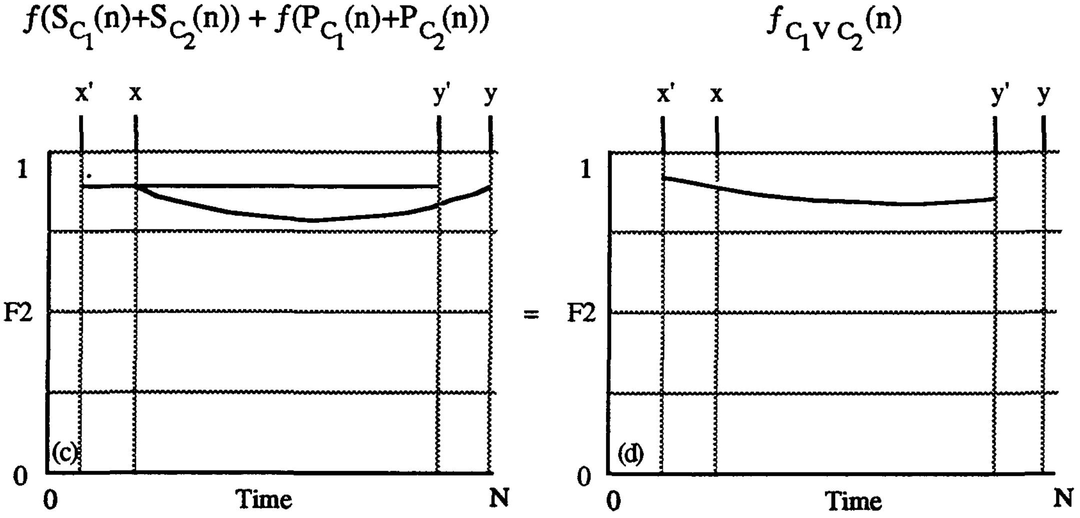
FIGURE 6.6. INTERACTION OF PRIMARY AND SECONDARY CONSTRICTION EFFECTS IN THE SYMMETRIC CONTEXT /p^jVp^j/



The time domain t of $f(S_{C_1}(n) x S_{C_2}(n))$ is defined as t=(y-x). The time domain t' of $f(P_{C_1}(n) x P_{C_2}(n))$ is defined as t'=(y'-x'), where x' corresponds to release and y' corresponds to closure. This delay in timing between the primary and secondary articulations is reflected in Figure 6.6c where $f(P_{C_1}(n) x P_{C_2}(n))$ has been superimposed on $f(S_{C_1}(n) x S_{C_2}(n))$. Assuming that the latency of the secondary constriction effects obtains in both syllable positions, the effect of $f(S_{C_1}(n) x S_{C_2}(n))$ will be different at closure than at release, resulting in different values for F2. This is illustrated in Figure 6.6d. Crucially, The subordinate status of $f(P_{C_1}(n) x P_{C_2}(n))$ to $f(S_{C_1}(n) x S_{C_2}(n))$ in determining the trajectory shape is illustrated further in Figure 6.7 in which the interaction between secondary constriction and primary constriction effects is represented for the asymmetric context $/p^jVp^{\gamma}/$. Observe that the primary articulation function is tilted in proportion to the slope of the secondary articulation function. In other words, secondary articulation defines the region in the parameter space through which the F2 trajectory will traverse. Primary articulation contributes some curvature to this trajectory, but does not significantly alter the slope of the F2 trajectory which is defined by $f(S_{C_1}(n) x S_{C_2}(n))$.

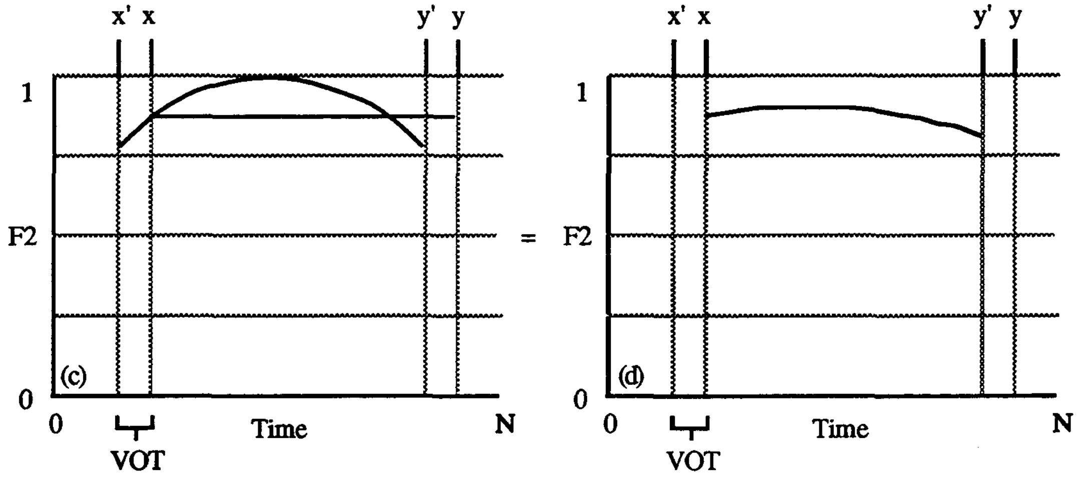
The sample 'derivations' illustrated above involved the effects of secondary palatal constriction. The same generalizations obtain for secondary velarized constriction, except that the effect of constriction size would be concave instead of convex (cf. Figure 3.8). The resulting trajectory shape is predicted to be approximately the same since the primary articulation function defines the final curvature of the trajectory. When the primary constriction involved is in the alveolar region, $f(P_{C_1}(n) x P_{C_2}(n))$ is hypothesized as defining a linear function, as illustrated in Figure 6.8. This is based on the assumption that alveolar constriction has a neutral effect on F2 (cf. Figure 6.2). The offset of the secondary constriction effects, however, still predicts that F2 should differ in the onset and offset positions.

FIGURE 6.8. INTERACTION OF PRIMARY AND SECONDARY CONSTRICTION EFFECTS IN THE SYMMETRIC CONTEXT $/t^jVt^j/$



F2 was often not measurable until voice onset (more so with the bilabials than the alveolars), so that there is some lag between the initial F2 value that was measured and actual release of closure. This would result in an asymmetry in F2 at the onset and offset, even if we posit a purely linear $f(S_{C_1}(n) \times S_{C_2}(n))$, as illustrated in Figure 6.10. While this is a possible explanation for the consonantal locus asymmetries, it is not a probable one due to the very short VOT exhibited by the data, especially for the bilabial consonants.

FIGURE 6.10. HYPOTHETICAL EFFECT OF VOICE ONSET TIME ON OBSERVED F2 VALUES



The model that has been presented captures the variation in F2 without reference to a vocalic F2 target. In this respect, it differs from other models of CVC formant contours. For example, Broad & Clermont (1987) propose an additive model of the form

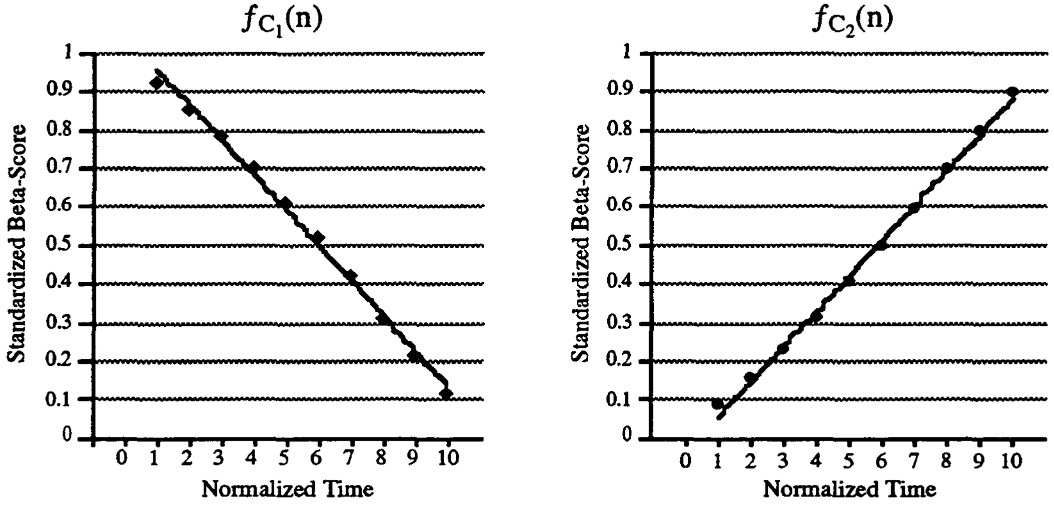
$$F_{C_1VC_2}(n) = f_{C_1V}(n) + T_V + g_{VC_2}(n) \qquad (2)$$

for English. The medial vowel target is crucial to the model, and there is a sense in which it is constructed around the vocalic target, since both f and g are transitions functions based on C-to-V and V-to-C interactions. Of course, the difference between Broad & Clermont's model and the model proposed in (1) is due to the nature of the phonological systems they are based on, and the concomitant phonetic differences which they are trying to capture. Contrast along the front/back parameter for vowels is phonemic in English; in Marshallese, it is not.

Broad & Clermont's model does have an advantage in its applicability to F1, F2 and F3. The model in (1), proposed for Marshallese, on the other hand, is specific to F2. It

Lastly, the relative contribution of the initial consonant, expressed as $f_{C_1}(n)$, and final consonant, expressed as $f_{C_2}(n)$, in the secondary and primary articulation functions (i.e., the relative timing of C_1 and C_2) is illustrated in Figure 6.9. $f_{C_1}(n)$ is a linearly decaying function, and $f_{C_2}(n)$ is a linearly increasing function. These function estimates are based on the beta-coefficients taken from the standardized z-score form of the regression equations in Chapter 3 (cf. Figure 3.20 and Figure 6.1). However, whereas the slopes in Figure 3.20 differ slightly across the two linear functions (C_1SLOPE=-0.0913; C_2SLOPE=0.0915) in the acoustic data, the slopes are the same in the proposed model. The asymmetries that are observed in the acoustic data, reflected by the slight difference in slopes in these functions, is derived instead by the relative timing of the primary and secondary articulations in the idealized model.

FIGURE 6.9. INITIAL AND FINAL CONSONANT FUNCTIONS REFLECTING THE MAGNITUDE OF THEIR RELATIVE INFLUENCE THROUGHOUT THE VOWEL

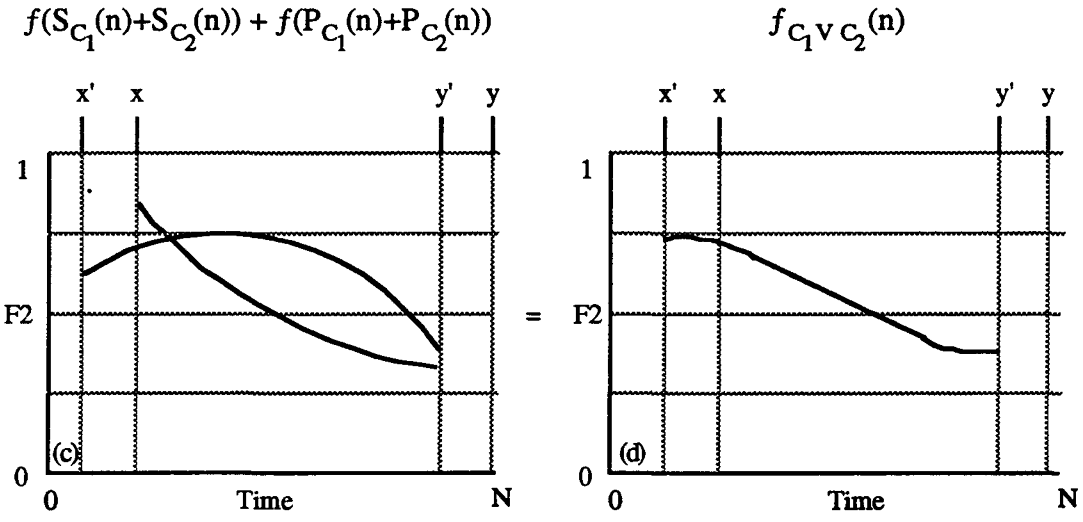


There are two other factors which may be contributing to the consonantal locus asymmetries. The first is related to $f(P_{C_1}(n) x P_{C_2}(n))$ which is idealized as a symmetric function in the examples provided above, an idealization which may not be true (cf. Kuehn & Moll (1976) for differences in C-to-V and V-to-C velocity in English). If the effects of primary place of articulation are asymmetric, then this will effect the F2 values at the onset and offset position as well.

The second factor is related to voice onset time (VOT). This is illustrated in Figure 6.10, where the release of closure is defined as x' and voice onset is defined as x. Therefore VOT=x'-x and the acoustic (observed) vowel duration T is defined as T=(y'-x).

the effects of constriction size is delayed relative to consonant closure due to its affiliation with the effects of secondary constriction. It is in this way that the effects of secondary articulation dominates after release, while primary dominates before closure. This is an important aspect of the proposed model; it does not require target-adjustment rules to account for the consonant F2 locus asymmetries. Rather, target variation is derived as a function of relative timing.

FIGURE 6.7. INTERACTION OF PRIMARY AND SECONDARY CONSTRICTION EFFECTS IN THE ASYMMETRIC CONTEXT /pʲVpˠ/



$f(S_{C_1}(n)+S_{C_2}(n)) + f(P_{C_1}(n)+P_{C_2}(n))$

$f_{C_1 V C_2}(n)$

All else being equal, the contribution of primary articulation is interpreted as subsidiary or minor to that of secondary articulation in defining F2. It is true that the convex shape of the trajectory is contributed by $f(P_{C_1}(n) \times P_{C_2}(n))$. However, this contribution is superimposed on a trajectory defined in the F2 space by $f(S_{C_1}(n) \times S_{C_2}(n))$. In the example illustrated in Figure 6.6, the feature [PALATAL] projects F2 targets that are close to 1 in value (on a scale from 0 to 1) so that $f(S_{C_1}(n) \times S_{C_2}(n))$ defines a trajectory that is high in the F2 space. If the secondary articulations were symmetrically velar, then $f(S_{C_1}(n) \times S_{C_2}(n))$ would define a trajectory low in the F2 space, since the values associated with velar targets are closer to 0 in value. It is in this sense that $f(S_{C_1}(n) \times S_{C_2}(n))$ is claimed to be the major component in defining the F2 trajectory through the vowel; the position of the trajectory in the frequency domain is defined by the F2 targets projected by the secondary articulation features, coupled with the effects of aperture increase associated with vowel height as in Figure 6.5. $f(P_{C_1}(n) \times P_{C_2}(n))$ then shapes this trajectory.

could be generalized to include F1 by adding a vowel target T_V and stipulating that $T_V=0$ for F2:

$$F_{C_1VC_2}(n) = f(S_{C_1}(n) x S_{C_2}(n)) \bullet f(P_{C_1}(n) x P_{C_2}(n)) + T_V \qquad (3)$$

The underspecification hypothesis is still captured by (3) in so far as there is a parameter T_V and $T_V=0$ when the formant frequency in question is F2, otherwise $T_V \neq 0$. Alternatively, T_V for F2 could be defined as a function of vowel height to capture the weak, but significant, effect at the vowel midpoint discussed in section 3.4.1.2.

$$T_V(n) = f(F1(n)) \qquad (4)$$

However, this is unnecessary as the effects represented by (4) were incorporated into the $f(S_{C_1}(n) x S_{C_2}(n))$ function, which better captures the fact that the F2 values are predominantly determined by the effects of the secondary articulations, coupled with the effects of vowel height.

6.5. *REPERCUSSIONS FOR PHONOLOGICAL THEORY*

The discussion of underspecification in this dissertation has focused on its instantiation in the phonetic domain. By implication, the phonetic evidence has been used to posit phonological underspecification in Marshallese, represented in terms of the absence a featural specification for the front/back parameter. The analysis that has been proposed, however, runs counter to many phonological theories, in so far as it is generally assumed that representations are fully specified, via redundancy rules, prior to exiting the phonology. If underspecification persists into the phonetic component, then the existence of such redundancy rules is brought into question. This has been acknowledged by Archangeli (1988: 189), who states, "The conclusion to be drawn from ... phonetic evidence is that complete specification cannot be a necessary condition on the output of the phonological component/the input to the phonetic component." The weaker claim is that redundancy rules assigning default values exist, but that they are not universal. This non-universality can extend to two levels: first, the application of such rules may be language-specific, and second, they may be restricted to a subset of the distinctive features. Much research remains to be done to explore these hypotheses.

In the case of Marshallese, these questions are intricately meshed with the vertical nature of the underlying vowel system and the complementarity in the distribution of height and front/back features in the phonemic inventory (i.e., the vowels contrast for height, and the consonants contrast for front/back). Marshallese may be a language, not in which one of the possible binary values for a feature [±BACK] is *absent* in the underlying vowel matrix, but rather, a case in which the feature *does not obtain* in the vowel matrix at all, much in the same way, e.g., that the features [±TENSE] and [±ATR] are not utilized by all languages. This runs counter to conventional wisdom in which [±BACK] is traditionally associated with vowels, but there is no principled reason provided by phonological theory that this must be the case. The data examined in this dissertation, however, cannot be taken as conclusive evidence for a purely vertical vowel system - the question of the long vowels remains. If the phonetically long vowels are derived, as Bender suggests, then the claim that [±BACK] does not obtain in the vowel matrix can be maintained. The alternative analysis in which length is phonemic would require that [±BACK] be defined in the vowel matrix.

Regardless, the analysis of the short vowels presented here is not affected. In Marshallese, [±BACK] is wholly redundant for its short vowels, and this redundancy is dynamically derived in the phonetic component and not by static phonological redundancy rules. We may extrapolate further and state that not all allophonic variation is phonological in nature, and that other assimilation processes hitherto analyzed in phonological terms (e.g., epenthetic vowel coloring) might be re-examined in the methodological and theoretical framework that has been used here.

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